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# MODELING OPERATIONS OTHER THAN WAR: NON-COMBATANTS IN COMBAT MODELING

by

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Submitted in partial fulfillment
of the requirements for the degree of

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## ABSTRACT

This thesis describes essential modeling requirements for Operations Other Than War (OOTW). It includes discussions of the Future Theater Level Model (FTLM); a developmental combat model. This thesis also includes discussions of OOTW and a specific OOTW scenario: Operation RESTORE HOPE. This thesis proposes model attributes for non-combatants in a combat theater based on the supposition that non-combatants are an essential feature in OOTW. The model proposal includes a methodology for civilian unit decision making. The model also includes proposals for modeling attrition caused by starvation, and attrition resulting from collateral effects of combat, as well as submodels for rioting, terror attacks, and unit flight from combat. Finally, this thesis includes a numerical example of some modeling aspects in a limited scenario.

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## EXECUTIVE SUMMARY

### I. INTRODUCTION.

This thesis addresses the needs of Army and Joint staffs for a combat model that explicitly portrays aspects of modern combat in Operations Other Than War (OOTW). OOTW include everything in the spectrum of military operations except for unrestricted theater-level warfare. OOTW include counterinsurgency, disaster relief, counterterrorism, counterdrug operations and a variety of foreign nation support activities.

This thesis is a partial answer to a need expressed by U.S. Army planners to develop models to examine post Cold War situations. The U.S. Army agencies who have specifically expressed interest in the results of this thesis include U.S. Army TRADOC (Training and Doctrine Command), The Louisiana Maneuvers (LAM) Task Force, and J-8 (CFAD) of the JCS staff.

This thesis focuses on modifying FTLM (Future Theater Level Model) to include the ability to explicitly portray key aspects of OOTW (Operations Other Than War). The model version that results from this thesis effort is referred to as OOTWTLM (Operations Other Than War Theater Level Model), while the term FTLM refers to that model without OOTW modifications.

This thesis presents model proposals for modifying FTLM to address some specific aspects of OOTW. The thesis specifically addresses key aspects in OOTW as demonstrated in Operation RESTORE HOPE, Somalia. These issues include several aspects of modeling the effects of non-combatants in a combat theater.

### II. BACKGROUND.

This thesis provides background information on FTLM, OOTW and the situation in Somalia. FTLM refers to the December 1993 version of the model. Changes to the model as a result of this thesis are described in Chapter III. OOTW includes five primary operations. Chapter II briefly describes those operations and discusses the major features of OOTW. Chapter II also provides information describing the scenario in Somalia,

including a brief history of the events leading up to U.S. involvement in Somalia, an explanation of why FTLM is suitable for this modeling effort, and a description of the forces and terrain involved in Operation RESTORE HOPE.

## III. PROPOSED MODEL.

This thesis proposes to model non-combatant behavior in a combat theater as homogeneous civilian units.

**A. CSI, CIVIL STABILITY INDEX.** This is a measurement of the stability of the population as a whole.

**B. NEW ATTRIBUTES FOR CIVILIAN UNITS.** These new attributes are heuristic attempts to quantify the utility functions of civilian units and players. They include indices for hostility, irrationality, the desire to gain ground and/or hold ground, and the desire for self preservation. The attributes of civilian units also include the number of unarmed personnel, the amounts of various supply categories, production rates for those supplies, and a starvation history of the unit.

### C. CIVIL DECISION MODEL.

The Civil Decision Model is a heuristic approach to determining civilian unit actions as a function of each unit's individual utility functions and circumstances. This model uses the indices that quantify each player's goals and desires to change the probabilities of a civilian unit selecting one of several actions. The model then describes submodels for portraying civilian actions that result. Those actions include rioting, terrorist attacks, limited attacks, flight from combat, and civilian defense.

### D. ATTRITION BY STARVATION AND DISEASE.

This model calculates attrition resulting from starvation and disease using the unit starvation history to determine an attrition coefficient which is then used to determine the mean value and variance for a normal random number. The attrition from starvation and disease will be a scaler multiple of the results of the normal random number draw.

## E. ATTRITION BY COLLATERAL EFFECTS OF COMBAT.

These attrition calculations are scaler multiples of damage done to target units as a result of Lanchester equations in FTLM The intent of this section is to provide a heuristic approach to calculating collateral attrition. The scaler multiple is a representation of the ability to the firing unit to discriminate the target from non-targets present in the same node, as a function of target and munitions characteristics. This section also presents an alternative analytical approach.

## F. LOGISTICS CONSIDERATIONS OF CIVILIANS.

In addition to having the same logistics considerations that military units have, civilian units have three additional considerations. The presence of civilian units in the combat theater present situations where assets can be transferred, can be abandoned, or can be produced in the theater. This thesis proposes methods for modeling each of these situations.

# IV. NUMERICAL EXAMPLE.

Chapter IV provides a numerical example of the procedures described in Chapter III. The numerical example uses an abbreviated scenario, with features of Operation RESTORE HOPE, to demonstrate many of the essential model characteristics. The numerical example depicts seven units from three players interacting on a terrain representation consisting of four nodes and four arcs. Where the model calls for random number selection, numbers are intentionally selected to produce results that will demonstrate model features. The Civil Decision Model results are displayed as probabilities of occurrence for each possible civilian decision.

# V. SUMMARY AND FUTURE STUDY.

The numerical example demonstrated that the model appeared to perform in an acceptable manner, in that it produced output within a reasonable range. During the calculations for the numerical example, some adjustments were made to arbitrary parameters to correct for model outputs that were not in a reasonable range.

This thesis is an initial step in an area that is not well researched. As such, there are many related areas available for future study. Work on this thesis suggests future work in dynamic route improvement, piecemeal unit movement, fitting parameters to historical data, and deception operations.

# I. INTRODUCTION.

## A. PROBLEM BACKGROUND: MODEL REQUIREMENT.

This thesis addresses the needs of Army and Joint staffs for a combat model that explicitly portrays aspects of modern combat in Operations Other Than War (OOTW). OOTW includes everything in the spectrum of military operations except for unrestricted theater-level warfare. OOTW include counterinsurgency, disaster relief, counterterrorism, counterdrug operations and a variety of foreign nation support activities.

### 1. Why a model is needed.

Following the end of the Cold War, U.S. Army and Joint staffs discovered that existing combat models were not adequate to model post Cold War situations. The U.S. Army's capstone doctrine manual, FM 100-5, Operations [Ref. 1], states in its introduction:

> The 1993 doctrine reflects Army thinking in a new, strategic era. This doctrine recognizes that the Cold War has ended and the nature of the threat, hence the strategy of the United States as well, has changed. . . It causes AirLand Battle to evolve into a variety of choices for a battlefield framework and a wider interservice arena, allows for increasing incidence of combined operations, and recognizes that Army forces operate across the range of military operations.

Inherent in the above statement is the need for Army planners to have modeling tools to assist their analysis of combat operations in post Cold War situations. Presently, the combat models used by Army planners, (VIC and CEM) rely on common Cold War assumptions: linear battlefield, ease of friend/foe recognition, and absence of "distractors" on the battlefield. Those models were adequate when the battlefield assumptions above were true. In operations other than war, it is known that those assumptions may not be true. Therefore, another modeling tool is needed.

### 2. Who needs a revised model?

Three major organizations have expressed a need for this model and provided support for its development: U.S. Army TRADOC (Training and Doctrine Command),

The Louisiana Maneuvers (LAM) Task Force, and J-8(CFAD) of the JCS. As the Army's chief analysis and doctrine writing organization, TRADOC has expressed a desire for a new model for use in future doctrine development and combat planning analysis. GEN Franks, the commander of TRADOC, described FTLM as "...a future model that will allow us to look at the current strategic landscape in ways that some of our current models can't do" [Ref. 2]. The LAM Task Force has the mission to evaluate the Army's current doctrine and tactics with regard to their usefulness in the post Cold War world. That task force has shown interest in this thesis research.

## B. FOCUS OF THESIS.

This thesis will focus on modifying FTLM (Future Theater Level Model) to include the ability to explicitly portray key aspects of OOTW (Operations Other Than War). The model version that results from this thesis effort will be referred to as OOTWTLM (Operations Other Than War Theater Level Model), while the term FTLM will refer to that model without OOTW modifications.

## C. SCOPE OF THESIS.

This thesis presents model proposals for modifying FTLM to address some specific aspects of OOTW. The thesis does not make claims for the strengths or weaknesses of FTLM except as necessary for understanding modeling issues endemic to OOTW. This thesis specifically addresses key aspects in OOTW as demonstrated in Operation RESTORE HOPE, Somalia. These issues include several aspects of modeling the effects of non-combatants in a combat theater. Although many of these proposed models and formulas can be applied to other combat models, they were developed for the specific example of disaster relief operations in Operation RESTORE HOPE. Many of the methods described in this thesis are based on a heuristic approach to modeling the complexities of OOTW instead of an algebraic approach.

## D. THESIS CONTENTS.

Chapter II provides background information on FTLM, OOTW and the situation in Somalia FTLM described in this chapter refers to the December 1993 version of the model. Changes to the model as a result of this thesis are described in Chapter III. OOTW includes five primary operations . Chapter II briefly describes those operations and discusses the major features of OOTW. Chapter II also provides information describing the scenario in Somalia, including a brief history of the events leading up to U.S. involvement in Somalia, an explanation of why FTLM is suitable for this modeling effort, and a description of the forces and terrain involved in the operation.

Chapter III describes the new modifications to FTLM that allow it to portray key aspects of OOTW as they apply to the situation in Somalia. Specifically, the model has enhancements that allow it to portray actions of non-combatants. The proposed model includes heuristic methods for non-combatant units to select actions. This chapter also describes methods for calculating attrition due to starvation and disease, and for attrition due to collateral effects of combat. Also included are details for submodels that represent civilian unit rioting, terrorist attacks, flight from combat, and limited attacks.

Chapter IV shows a numerical example of a limited scenario. The limited scenario depicts movements and actions of seven units, from three sides, on four nodes, to demonstrate the functions of the OOTW-specific capabilities in the model. The example progresses through three steps within which each of the OOTWTLM model characteristics that are developed in Chapter III are demonstrated.

Chapter V summarizes the thesis and discusses areas for future study.

# II. BACKGROUND.

## A. INTRODUCTION

Chapter II provides background information on FTLM, OOTW and the situation in Somalia. FTLM as described in this chapter refers to the December 1993 version of the model. Changes to the model as a result of this thesis are described in Chapter III. OOTW includes five primary operations . Chapter II briefly describes those operations and discusses the major features of OOTW. Chapter II also provides information describing the scenario in Somalia, including a brief history of the events leading up to U.S. involvement in Somalia, an explanation of why FTLM is suitable for this modeling effort, and a description of the forces and terrain involved in Operation RESTORE HOPE.

## B. FTLM MODEL DESCRIPTION.

This section describes some of the major features of FTLM, namely the December 1993 version. The principal modeling efforts of this thesis are described in Chapter III. For more details on the December 1993 version of FTLM, see [Ref. 3].

### 1. Stochastic processes.

FTLM uses stochastic processes to model events that are common in combat models. This characteristic of the model has two major strengths. First, because the model does not deterministically calculate outcomes, the model can produce different outcomes on subsequent model runs with the same inputs. This ability provides more realistic outcomes because a set of 50 or more model runs will produce a range of outcomes that would more credibly represent actual variability. This allows decision makers to weigh the consequences of unlikely (but possible) events.

Secondly, the inputs for the model consist of means and variance parameters. This allows the model to describe the characteristics being modeled throughout their entire range of possible values rather than by simple point estimates.

### 2. Perception based.

FTLM differs from most existing models in that it is perception based. Within the model, decisions are made based on player perceptions of enemy strengths and dispositions; error in such perceptions is explicitly modeled. This aspect of the model allows a realistic portrayal of intelligence gathering. Most other theater level models base decisions on a ground truth orientation; all players are assumed to know the true locations, types, and force sizes of opponents at all times. The players in FTLM only utilize the information that they have collected from imperfect intelligence sensors. The information gathered by the sensors is limited by the ability of the sensor and the number and characteristics of those employed by the model. Sensor information is fused with earlier information to create a better picture of the enemies' disposition.

### 3. Terrain representation.

The terrain in FTLM is represented by two networks: ground and air. Each network is a system of physical nodes and transit nodes. Transit nodes are the connecting arcs between physical nodes in a traditional network representation. For clarity, transit nodes are hereafter referred to as *arcs* and physical nodes are referred to as *nodes*. The ground network is a system of nodes that represent physical locations, and connecting arcs that represent mobility corridors between the physical nodes. The air network is a square grid network that allows aircraft to maneuver in eight major directions (N, NE, E, SE...) from any air node. Nodes in the air grid are evenly spaced over the range of the ground network. Each node is connected to the eight adjacent nodes by arcs which represent the principal directions of flight for aircraft.

Ground physical nodes can be of any size, and represent any point on the ground that is of interest to the model user. Nodes can represent anything from Seoul, Korea to a crossroad. Arcs represent the mobility corridors between nodes, and also have attributes. An arc can represent sea, roads, swamps, mountains or any other kind of terrain, and it can impose mobility and maneuver restrictions on the units using it. The attributes of an arc are values used over the entire length of the arc. This creates an arc with homogeneous attributes. If non-homogeneous attributes are desired, multiple transit

nodes can be used along a single mobility corridor. This aggregation greatly simplifies computation and computer memory requirements.

Because of the nature of the terrain representation as a node-arc structure instead of a digitized map or hex structure, the model user can select nodes and arcs that are of military significance and assign to them appropriate attributes. The model is not bogged down with superfluous digitized terrain information, nor does it have to contend with problems of obtaining digitized data on short notice for contingency areas.

### 4. User-friendly features.

At present, FTLM runs on a desktop computer with a 80486 processor. It runs in the Windows software environment and is programmed to interface with the user in an intuitive manner. The model is designed to allow analysts to create their own scenarios and run the model in their own offices, without outside programmer support.

## C. DESCRIPTION OF OPERATIONS OTHER THAN WAR (OOTW).

### 1. General.

OOTW includes all military and naval operations which are more limited than unrestricted theater-level war. Joint publications for OOTW are still in draft form, and some of the definitions are not completely compatible with the Army OOTW definitions. At the joint level, OOTW is referred to as *operations short of war*. Joint Publication 3-07 describes five doctrinal categories of operations short of war [Ref. 4]:

- Support for insurgency/counterinsurgency.
- Contingency operations short of war.
- Peacekeeping operations.
- DOD support to counterdrug operations.
- Combatting terrorism.

2. **Operations included.**

*a. Support for insurgency/counterinsurgency.*

This category of operations includes two subareas of support to insurgency and counterinsurgency. A key to accomplishing support for, or countering, an insurgency is understanding the political and ideological motivations and objectives of the contending parties [Ref 4: p II-1]. An example of support for insurgency was the operation by the Reagan Administration that supplied arms to the Contras fighting in Nicaragua in 1987.

*b. Contingency Operations Short of War.*

Contingency operations short of war are undertaken in crisis management situations requiring the use of military forces to enforce or support diplomatic initiatives, respond to emergencies, or protect U.S. lives [Ref 4: p V-1]. Contingency operations include: disaster relief, non-combatant evacuation operations, recovery operations, attacks and raids, freedom of navigation and protection of shipping, operations to restore order, and security assistance surges. Disaster relief actions were demonstrated recently by Operation RESTORE HOPE, and relief for Florida following Hurricane Andrew. Operation RESTORE HOPE will be examined in greater detail later.

*c. Peacekeeping.*

Peacekeeping includes peacekeeping support, observer missions, and peacekeeping forces. Peacekeeping support refers to providing financial or logistical assistance to peacekeeping operations. Observer missions assist in the observance and maintenance of a cease-fire; act as a neutral witness for the handing-over of personnel or property from one party to another; and other limited operations. Peacekeeping operations require the consent, cooperation and support of the authorities of all parties in the conflict [Ref 4: p IV-2]. An example of a peacekeeping operation is the U.S. observer mission in the Sinai Desert. The role of that mission is to observe the peace treaty stipulations of the Camp David Accords between Egypt and Israel.

*d. DOD support to counterdrug operations.*

This area includes a variety of missions including detection and monitoring, host-nation assistance, security assistance programs, civil-military operations and many special area support operations. Counterdrug operations usually are executed outside the U.S.; however, this category of operations also includes loans of equipment to U.S. law enforcement agencies and detection operations within U.S. boundaries [Ref 4: p VI-11]. An example of a counterdrug operation was the use of U.S. military units in Operation BLAST FURNACE in Bolivia in 1986, in which U.S. military helicopters ferried Bolivian anti-drug police to raids on secluded drug labs.

*e. Combatting terrorism.*

Combatting terrorism includes counterterrorism and antiterrorism. Counterterrorism, the offensive portion of combatting terrorism, provides measures that can include preemptive, retaliatory, and rescue operations. Antiterrorism is the preparation for defense against terrorism, including collection of threat information, security training programs, and implementation of sound defensive measures [Ref 4: p III-10]. An example of combatting terrorism was the U.S. action of bombing Libya for sponsoring the bombing of a civilian airliner over Scotland.

**3. Key features of OOTW.**

Although OOTW appear to cover a broad spectrum of operations, there are some key features common to all of them which will be described in greater detail in later paragraphs:

- Restricted rules of engagement (ROE).
- Uncertain security situation.
- Presence of non-combatants.
- Non-linear battlefield.
- Political dominance.

- Unconventional missions.
- Small units operating at theater level.

*a. Restricted rules of engagement (ROE).*

Since the primary purpose of most of the OOTW missions is not just killing enemy soldiers, the U.S. forces need to have restrictive rules of engagement (ROE). Such rules would prevent unnecessary bloodshed for all engaged forces. ROE in OOTW often prohibit the use of much of the U.S. arsenal, including air-delivered ordnance, high explosives, heavy armor, and artillery. Generally, the greater the explosive power an ordnance has, the greater the probability of unintended collateral damage to non-targets. For example, accurate delivery of a 2000 pound bomb onto a well-understood target would still inflict damage on non-combatants a city block away. Such collateral damage could prevent the U.S. forces from achieving victory.

*b. Uncertain security situation.*

Many of the OOTW missions require the cooperation of one or more non-U.S. forces. Peacekeeping, for example, requires the active cooperation of all warring parties in order to be successful. Since the decision to cooperate rests with the other players, the U.S. player is uncertain whether the required cooperation will materialize. In counternarcotic operations, the enemy may be indistinguishable from the non-combatants. Therefore, the U.S. forces may have to sacrifice some of their own security by not engaging possible targets at best effective range to make sure that they do not erroneously engage non-combatants. In many OOTW operations the enemy will be afforded the opportunity to shoot first. This will be true because friendly forces will be constrained from engaging targets that are not clearly identified as enemy. In OOTW, distinguishing enemy forces from non-combatants is very difficult. Conversely, because of U.S. uniforms and vehicle shapes and markings, the enemy will have no difficulty in identifying U.S. forces.

c. *Presence of non-combatants.*

One of the most significant characteristics of OOTW is the presence of non-combatants in the theater. Previous theater-level models implicitly assume widescale evacuation of non-combatants prior to hostilities, and proceed with a playing field occupied only by the opposing forces. OOTW will rarely have situations of mass civilian evacuation. In the case of Operation RESTORE HOPE, almost half of the civilian population was dislocated, but the remainder was still distributed throughout the theater and had an impact on combatant actions. Non-combatant forces in OOTW environments can become combatants on a limited scale. They can also assist combatant forces by providing intelligence or logistics support, or by providing disinformation to an enemy. Further, their presence can impede combat operations, or their well-being can be the objective of the military action.

The term *non-combatants*, in general, refers to those forces not in a uniformed army. In many cases, the civilian population can have their own arms and be organized for self defense. For example, in disaster relief operations after hurricane HUGO, U.S. forces encountered armed homeowners who were protecting their own property from looting. The local population also included police units that, while part of the civilian population, were and are equipped and organized for armed conflict at some level. The term *non-combatant* requires a broad definition so as to include those people who are not engaged in combat at a particular point in time, but who could be at a later time.

Non-combatants can contribute logistics and intelligence support to forces in the theater. Our own logistics doctrine now calls for the extensive use of host-nation support in future conflicts. In the case of counternarcotics operations, the U.S. force would be very dependent on the civilian population to help identify the enemy, which would otherwise be indistinguishable from that civilian population.

Finally, non-combatants take up space in the theater of operations. Their very presence influences combat operations. Civilian units moving on a road restrict the military traffic that also needs that road. The presence of civilians in a target area may

prohibit the U.S. forces from using their best ordnance packages to reduce the target and may instead incur greater risk for the U.S. forces.

*d. Non-linear battlefield.*

None of the OOTW missions include a scenario where a FEBA (Forward Edge of the Battle Area) defines the line between opposing forces. The OOTW environment may encompass a broad geographic region. The FM 100-5 terms *rear* and *deep* have little significance in a theater where every piece of terrain may be as likely as any other to be the focus of military action.

*e. Political dominance.*

Political events in OOTW dominate military events. Military forces exist in the theater to support political action. In many of the OOTW areas, finding and destroying enemy forces will not be enough to achieve the political theater objective. An example of this is the mission statement for U.S. forces in Operation RESTORE HOPE; "establish a secure environment for humanitarian relief operations." [Ref 6]

*f. Unconventional missions.*

Modern armies, as exemplified by the U.S. Army, are trained and equipped to fight a conventional theater war. Many of the actions called for in OOTW require skills for which U.S. forces have not been trained. For example, soldiers deployed to Los Angeles following riots in 1992 were required to participate in a law enforcement mission. Traditional roles of the infantry, such as attack or defend, were not appropriate in that environment. Similarly, in Operation RESTORE HOPE, the soldiers from the 10th Division were called upon to accomplish missions outside of their normal duties. Furthermore, many specialized units, such as civil affairs units and military police, may not be available when they are needed, requiring traditional combat forces to perform non-traditional missions.

*g. Small units operating at theater level.*

In most cases, OOTW does not require the deployment of several U.S. corps to a theater. Most OOTW operations can be successfully concluded using a brigade

size or smaller force. This creates a need for a theater-level model that can strike the balance between low and high resolution models to portray companies and battalions as the theater maneuver forces. For example, the French Foreign Legion has used a single platoon as a theater-level contingency force .[Ref. 5]

## D. SITUATION IN SOMALIA.

This section describes the general situation in Somalia, including the recent history of Somalia leading to Operation RESTORE HOPE and a discussion of the suitability of OOTWTLM to model that scenario. This section also includes descriptions of the terrain and forces as they will appear in the model.

### 1. History.

After 10 years of brutal dictatorship under President Barre, Somali rebels overthrew the Barre regime. At the end of the war, Somalia entered a period of anarchy with no central government. Starting in early 1991, drought and civil war displaced hundreds of thousands of Somali farmers and led to growing famine. International relief organizations were impeded by clan armies and independent armed bandits. Although tens of thousands of tons of food were brought to the country, little of it arrived in the interior of the country where the worst famine conditions prevailed. Much of the food that did arrive was stolen by the clan armies that controlled the port cities and bandits in the interior. It was estimated in December 1992 that 300,000 Somalis had died in the previous year; one quarter of the Somali children under the age of five had been killed [Ref. 6].

On Dec 3, 1992, the U.N. Security Council enacted resolution 794 "authorizing the use of all necessary means to establish as soon as possible a secure environment for humanitarian relief operations in Somalia." [Ref 6: p. 56] On Dec 4, 1992, then-President George Bush announced that the U.S. would send a substantial force of U.S. troops to Somalia. Troops began to arrive on 9 December. By mid-January, U.S. troop strength in Somalia and offshore had peaked at 25,000 and the number of troops from

other countries reached 11,000. The U.S. area of operations included parts of southern Somalia as shown in Figure 1.


Figure 1. Horn of Africa Showing U.S. Area of Operation.

### 2. Suitability for modeling in OOTWTLM.

OOTWTLM has several characteristics that make it suitable for modeling the OOTW situation in Somalia. The key features of OOTWTLM as described in section A above are the characteristics that are needed for this type of modeling.

#### *a. Terrain representation.*

The nature of terrain representation of OOTWTLM is ideal for depicting operations in Somalia. The terrain in Somalia has a few operationally significant points: cities and road networks. These cities and roads can easily be modeled as nodes and arcs. The terrain that is not included in the nodes and arcs above is littered with mines left over from the previous war, and is therefore impassable to most traffic without significant

engineer support.[Ref 6] The presence of mines on arcs is explicitly modeled as an attribute of the arc. Some possible arcs are not shown in the model because their mining is extensive enough to preclude their use, making them of no consequence in the model. This allows the significant aspects of this terrain to be modeled with fewer computer resources without sacrificing detail needed for useful validity in the model. Further, as an operation other than war, the situation in Somalia needs a model that can portray a non-linear battlefield where the locations and relative positions of opposing forces are not necessarily divided by a "line in the sand".

*b. Perception based.*

The perception based nature of OOTWTLM will allow unusual aspects of Operation RESTORE HOPE to be modeled. For example, this thesis proposes to model opposing force behavior that does not necessitate combat, but which may accidently lead to combat by opposing forces erroneously perceiving threats. For example, an aid convoy can look like an invading army if the circumstances are right.

*c. Stochastic processes.*

Since OOTW in Somalia were characterized by uncertainty, the stochastic nature of OOTWTLM provides an appropriate tool for modeling humanitarian relief operations in Somalia, as seen in Operation RESTORE HOPE. The uncertainty referred to includes transit times, unit compositions and courses of action, and performance of sensor and reconnaissance assets.

**3. Terrain.**

The terrain in Somalia is rocky and harsh. It has sufficient arable land under normal conditions, but food production is vulnerable to drought or war. A node-arc laydown that depicts the terrain for OOTWTLM is shown in Figure 2. The node and arc attributes are detailed in Appendix A. The information represented by the node and arc attributes are estimates from available information. Exact information is scarce, but the values shown should be sufficient to demonstrate the features of the model. The

determination of exact attributes is left for future study. The estimates were collected from a variety of sources including [Ref. 6]. The road types referred to in Figure 2 are an aggregation of the number and types of roads on the mobility corridor. See [Ref. 3, p. 127] for a detailed explanation.

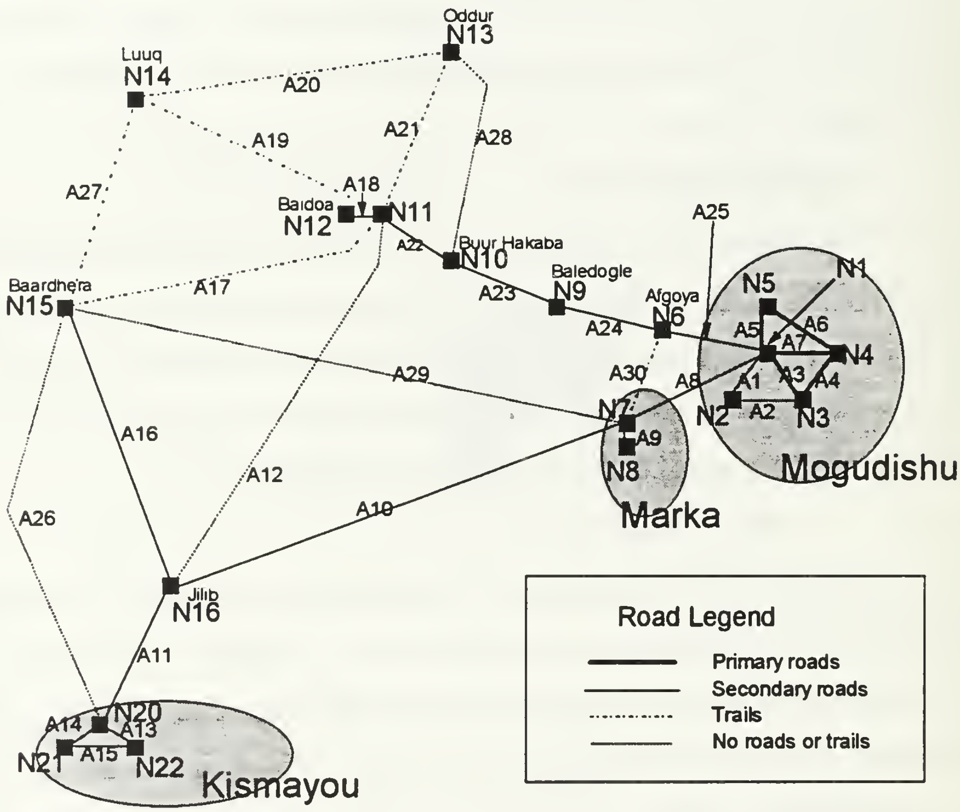



Figure 2. Node and Arc Terrain Representation.

### 4. Forces.

The forces in Somalia include those representing 13 major clans, each with several major subclans; almost 20 military forces from U.N. member countries and about 50 Non-Government Organizations (NGO). Among the Somalis, the clan forms the basis for political and military power. The clans are armed with the remnants of Somalia's defunct armed forces, and constantly fight among themselves. Within the U.S. area of operations,

the population can be divided into two major groups: populations loyal to Aideed, and populations not aligned with Aideed. For purposes of this model, foreign forces and NGOs will all be modeled as part of the BLUE (U.S. player). The two domestic groups described above will be modeled as two distinct players. Each player represents a near-homogeneous force for purposes of considering likely actions and attributes.

# III. PROPOSED MODEL.

## A. GENERAL.

This section describes the enhancements to FTLM, resulting in OOTWTLM, that are specific to this thesis. To model the situation found in Somalia, the scope of all OOTW operations was limited to deal only with disaster relief operations where military action is possible. The following sections describe the details for the model in areas that are specific to the Somalia situation.

The model characteristics described in this chapter document heuristic processes that are necessary to create systemic behavior for the non-combatant units. In other theater-level models, like the Joint Theater Level Simulation (JTLS), the functions modeled here are performed by human operators, making decisions for the unit throughout the execution of the model. OOTWTLM establishes algorithms to automate the responses of non-combatant units in a combat environment, based on quantified expressions of the goals, desires, and needs of the non-combatant player. The goals, desires, and needs are expressed as player attribute initial conditions in the model and are used in various combinations to effect the probabilities of civilian unit decision making. The bases of those quantifications are estimates of player goals and behavior described as scale values. Many of the algorithms and parameters are not data supported and are presented here as a starting point for future development.

## B. MODELING NON-COMBATANTS.

Modeling non-combatants in a combat theater poses several unique problems. Non-combatants have several attributes that field armies do not; they produce as well as consume supplies, they have the ability to contribute to combat forces, they impede maneuver, and only a small portion of their population will participate in armed action. Modeling non-combatants includes two areas: modeling the population as a system, and modeling the population as maneuver units. A Civil Stability Index (CSI) is proposed to

describe the effects of non-combatants as a system and several other rules for characterizing their behavior as maneuver units. The CSI is discussed in detail in section B.2

### 1. Defining opposing forces.

The term *player* refers to any group of units that is under the exclusive control of a single government having identical goals and objectives. All players in any theater are considered to be potentially opposing forces if their actions are determined independently. They are considered to be independent if the decision and command structure of each force does not cooperate with an opponent in determining future actions. Forces from several countries acting under a common command structure, such as the U.S. and U.K. operating under NATO command, are modeled as a single player, and not as opposing forces. On the contrary, the U.S. and the U.K. could be modeled as opposing players if they were not under a common command structure, even though they have no antagonistic mission. They should be modeled as opposing forces if, in modeling, it is determined that the U.K.'s independent actions substantially differ from the U.S.'s actions, and that independent action was important to the process being modeled.

### 2. The Civil Stability Index.

The Civil Stability Index (CSI) is a measure of the stability of the population as a whole. It is a number in the range 0.01 to 1.00, indexed by a linear scale with increments of 0.01. The lower values on the scale indicate anarchic instability, characterized by total breakdown of the any government or law enforcement, widespread looting, burning, and wanton destruction. The higher numbers on the scale indicate absolute stability in a well-ordered society, characterized by police not being necessary because citizens do not break the laws. Table 1 shows typical values for the CSI depending on observable conditions. The model user sets initial values for the CSI for each node using military judgement and the descriptions in Table 1 as a guide. The values in Table 1 were determined subjectively. They are used only to demonstrate the capabilities of the model, as it is influenced, and influences the CSI.

| CSI Number | Conditions |
|---|---|
| 0.15 | Rwanda, April 1994 |
| 0.25 | LA Riots, 1992 |
| 0.40 | South Africa, March 1994 |
| 0.50 | Washington, D.C. Urban housing, after dark. |
| 0.75 | Average day in any European city. |
| 0.85 | Average day in a U.S. small town in the midwest. |

Table 1. Sample CSI Value Representations.

The CSI for each node moves up and down according to the actions in the vicinity. The CSI is an attribute of each physical node, possibly indicating that conditions are getting better in one location, and worse in another. Table 2 indicates specific actions that take place in the model when thresholds in the CSI are crossed. For example, the threshold 0.15- means that whenever the CSI falls below 0.15, the U.S. is prohibited from conducting combat operations; the U.S. can resume combat operations when the CSI rises above 0.15. This threshold indicates that the CSI has fallen to such a low level that political forces in the U.S. "admit defeat" and decide to reduce their own losses by withdrawal. Each of the threshold levels in Table 2 indicate actions that occur in the theater as a result of the level of civil stability. The values shown in Table 2 are estimates for demonstrating the model. As the model development progresses these values can be changed if more suitable values are found. Further, additional model activities and thresholds can be added for other scenarios. The rationales for each of the thresholds listed in Table 2 are subjective and mainly applicable only to the Somalia scenario. Since they are not widely applicable, the rationales are not detailed in this thesis.

Table 3 indicates the actions of the model that produce an impact on the CSI. These two tables show that the CSI changes the model output and is changed by the operation of the model on previous CSI values with consequent reactions. Further, the CSI will be used to determine civilian action in Section 4.a. Values for use in future model versions might be elicited from intelligence specialists.

| CSI Threshold | Resulting Model Activities |
|---|---|
| 0.15- | - U.S. must cease offensive action |
| 0.20- | - Perform random draw each day against 10% chance that outside force requires U.S. to withdraw from theater. |
| 0.30- | - U.S. player prohibited from using area fire weapons. |
| 0.40- | - Transfer 2% of unarmed civilian unit personnel to armed personnel for each day CSI is below .40. |
| 0.60+ | - Civilians prohibited from supporting rebels with log/intel. |
| 0.65+ | - Transfer 2% of armed personnel per civilian unit to unarmed personnel. |

Table 2. Activity on Model Caused by CSI Thresholds.

| CSI Change | Impacts on CSI by Model Activities. |
|---|---|
| +0.01 | Per delivery of logistical support to civilian unit. |
| +0.01 | Per day without a starvation death. |
| +0.01 | Per day without a combat death. |
| -0.00007 | Per death due to starvation. |
| -0.0003 | Per death due to direct combat. |
| -0.0001 | Per death due to collateral damage. |
| -0.1 | Per incident of terror attack. |
| -0.05 | Per day of rioting, pro-rated for % of day. |

Table 3. CSI Activity.

### 3. Attributes and capabilities of non-combatants.

Since this thesis proposes modeling non-combatants as virtual military units, they will have all of the model attributes of military units already present in FTLM. Naturally, the values of the attributes should be significantly different from those of combat units. This section defines those attributes and capabilities that are specific to non-combatant units and those attributes that are needed to add to combatant units to enable OOTW operations.

The first six attributes are values on a continuous linear scale of 1 to 5. These attributes will be used singly and in combination later in this chapter to determine actions by civilian units in the Civil Decision Model. This linear scale is set as an initial condition in the game and does not change throughout play. The values used for each of these attributes are derived from estimates by military intelligence analysts. Although a linear scale is used in this model, a more realistic model would include a non-linear utility function. For example, a player's desire to hold terrain could increase after he has lost substantial terrain already, and he is in the position of making a "last stand". Table 4 summarizes the attributes and their ranges.

| Name | Description | Range | Attribute of | Section |
|---|---|---|---|---|
| CSI | Civil Stability Index | 0.0-1.0 | Node | 2 |
| IRI | Irrationality index | 1-5 | player | 3.c. |
| HI | Hostility Index | 1-5 | player | 3.a. |
| GG | Desire to Gain Ground | 1-5 | player | 3.b. |
| HG | Desire to Hold Ground | 1-5 | player | 3.d. |
| PF | Desire to Preserve Force | 1-5 | player | 3.e. |

Table 4. Summary of Model Attributes.

#### *a. Irrationality Index (IRI).*

This attribute is used to calculate the variance parameter in a random number draw from a normal distribution in the Civil Decision Model. It is used to determine what actions a civilian unit will select in the Civil Decision Model. The irrationality index represents the degree to which the U.S. player feels that his opponent is irrational. A value of one indicates very rational and translates to a variance of 1/25 in the normal random number draw. The value of the variance is IRI /25. The constant 25 is used because it results in a normal curve within the possible range for IRI as described later. The IRI will result in a greater unpredictability of action when the enemy

is considered to be irrational, and a smaller variance when the opponent is considered to be rational. The IRI is a user-input, based on the military judgment of the model user.

*b. Hostility Index (HI).*

This attribute describes each player's predisposition to hostile action against another player. It is expressed as a global, initial condition. It is used in concert with other model attributes to determine civilian unit actions. Of itself, it does not cause or prevent hostile action in the same way that ROE (Rules of engagement) would. Each player has one of these scores for each of the other players in the game to indicate their feelings toward each of the other players. Low values indicate that the player has a low hostility or friendly attitude towards a particular player. Players with a low score are more likely to cooperate with that opponent. High values indicate that the player is very hostile to an opponent and is likely to fight against him if they encounter each other and tactical conditions are favorable. The hostility index of one player to another need not be a reciprocal relationship. For example, U.S. forces in Somalia did not consider themselves to be hostile to any other player in the theater, yet it is known that some of the Somali factions were hostile to the U.S.

*c. Desire to Gain Ground (GG).*

This attribute evaluates the player's desire to expand his territory by sending military forces into neighboring nodes. The higher the score, the more desirous the player is of following an expansionist course of action. This desire, when linked with other model parameters, determines when a player may send his forces out to seize ground in a military action. Civilian players will normally have low values for this attribute.

*d. Desire to Hold Ground (HG).*

This attribute evaluates the player's desire to keep the terrain he has. This is a measure of the player's desire to stand and fight when threatened instead of fleeing.

This score is on a continuous linear scale from one to five. A high score indicates a strong desire to hold ground.

*e. Desire to Preserve Force (PF).*

This is the measure of a player's desire for self preservation. Some armies of the world advertise their "to the last man" mentality. Those armies would be indicated by a scale value of one. On the other hand, the U.S. has a reputation, particularly in OOTW, to cease operations after casualties reach a very low threshold. For example, the U.S. policy of assistance in Somalia was severely questioned in the U.S. press when two aircraft were shot down, a dozen U.S. soldiers killed, and one soldier was taken prisoner. This media attention to casualties in a humanitarian assistance operation arguably resulted in the Clinton administration's decision to set a withdrawal date for U.S. forces. U.S. forces engaged in OOTW will generally have a value of four or higher. A value of five indicates that the force will flee in the face of perceived future casualties.

*f. Number of unarmed personnel.*

This parameter is separate from the "Personnel" parameter already in the model. The "Personnel" parameter will be replaced by two parameters: number of armed personnel, and number of unarmed personnel. Civilian units will have a majority of unarmed personnel and a small percentage of armed personnel, replicating police and armed citizens. This structure is needed because unarmed population groups can receive all of the effects of combat without contributing to it. When a civilian unit attacks a military unit, only their armed personnel give and receive casualties. This is due to the assumption that unarmed personnel do not participate in the action. Unarmed personnel are still available to receive casualties resulting from collateral effects of combat, as described in section B.6. Unarmed personnel are able to participate in non-combat hostile actions, such as riots and terrorist attacks.

*g. Number of weapons systems (by system type).*

This parameter is similar to the model parameter of "Equipment" that is currently in the model. In many OOTW, non-combatants are sometimes well armed and equipped.

*h. Amount of supplies (by type of supply).*

These parameters are like those already in FTLM for the play of the logistical aspect of the model. This includes separate attributes for each major class of supply (I, III, V, and other). Classes of supply are distinguished because ownership and consumption of food is more important in OOTW than consumption of ammunition. The logistic play in the model, therefore, needs to distinguish between these types of supply.

*i. Production rate.*

For each class of supply, civilian units are capabile of producing supplies at some daily rate. Civilian units control local agriculture, processing and manufacturing. When there is some level of stability present, the population will continue to produce food and other classes of supply, to include major end items (trucks, tanks, and aircraft). This parameter can also be used by military log units to portray the arrival of supplies in the theater from an outside source.

*j. Ten-day starvation history of a unit.*

This attribute is actually an array of ten elements. The $i^{th}$ element of the array is the percent of personnel who have not received food (defined here as starvation), for i consecutive days. $X_1$ is the percent of personnel at starvation one day ago and is calculated at the beginning of each day by

$$X_1 = 1 - MIN\left(1, \frac{Food\ Available}{(FCR)(Total\ Personnel)}\right). \tag{1}$$

Values for $X_2$ through $X_{10}$ are carried forward from one day to the next by advancing the previous day's calculation through the array. In equation (1), FCR is the food consumption rate of the unit, per person, per day. A 14 or 20-day starvation history could

easily be used instead of this ten-day cycle. The ten-day history is used to limit memory requirements for operation of the demonstration model. Each unit should have an FCR assigned that is appropriate for the unit type. Normality assumptions for civilian population units have been used in this model to aggregate an FCR over all age and activity level subgroups in the civil unit. Normality with regard to the civilian population means that each population unit includes a heterogeneous mix of races, ages, genders, and vocations, so as to have representative proportions of the population at large. The starvation history is used for determining attrition due to starvation as described in section B.5.

### 4. Behavior of civilians.

It may be reasonable to model civilian behavior on the battlefield with a greedy and myopic utility algorithm. It is assumed that civilian actions are determined by their perceived surroundings out to a distance of one node away. This distance could be greater so as to indicate a well organized society that includes reliable telephone, radio, and television networks, and that has dedicated sensors (spies) at distant nodes. Figure 3 shows the basic diagram for determining the actions of civilian units. This diagram shows heavy reliance on the core FTLM structures. Those actions that are not part of the core FTLM model are discussed individually as submodels later in this chapter. The following sections describe the decisions made in submodels for specific civilian actions.

#### *a. Civil Decision Model.*

This decision model assumes that the decision makers for the civilian units are rational according to some utility function of their own. The IRI is more a function of the error of the U.S. player's ability to predict its opponent's utility function than a declaration of the opponent's rationality. The stochastic features of FTLM have been extended to determine the actions of civilians. The stochastic decision process gives the civilian units the ability to make either poor decisions or good decisions with probabilities appropriate to their initial input values and the model situation. The Civil Decision Model defines the spectrum of possible choices and assigns probabilities to each possible choice. The probabilities change dynamically from day to day depending on individual

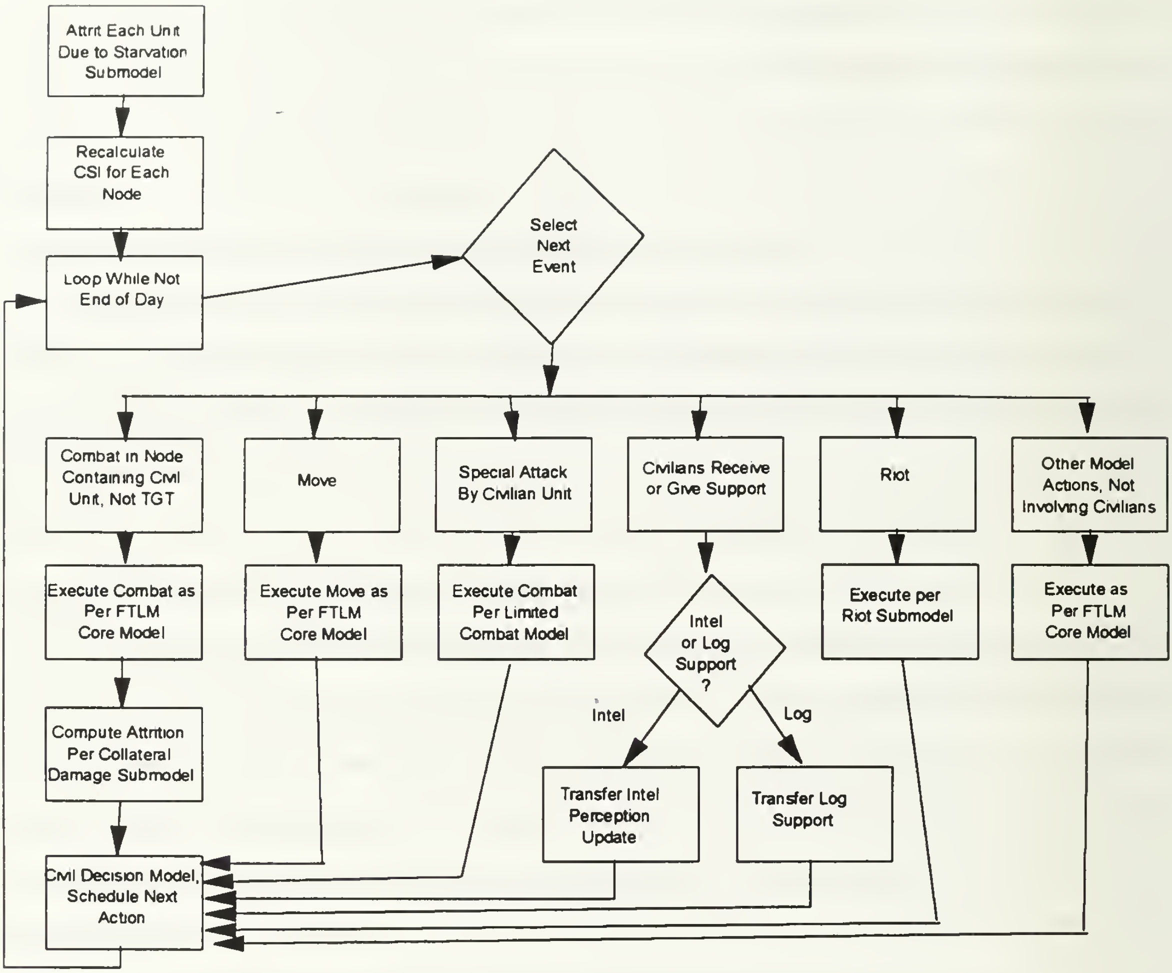



Figure 3. Basic Model Daily Decision Cycle.

players' perceptions of other players, and the values that each player assigns to the attributes listed in section 3 above.

Figure 4 shows the decision space and decision regions for civilian unit actions. In Figure 4, variables *a* through *e* are boundary levels between the decision regions **R,T,L,F,D,** and "Do Nothing". The sizes of the decision regions change as a result of actions in the model and represent the relative probability of that action occurring. The sizes of each of these regions are determined by equations (2) through (9) and are indicated by bold faced lettered designations. The actual selection of the action in the decision space is based on a random draw from a normal distribution with parameters of mean = CSI and variance = IRI / 25, as described in subsection (7).

Randomness in this action selection represents the probability that some leaders make poor choices and sometimes the choices are based on utility functions that are poorly understood by their opponents, thus appearing irrational. This is intended as a tentative structure.

Figure 5 shows the Civil Decision Model algorithm. The details of the Civil Decision Model selection process are shown in subsection (7). The formulas that influence the sizes of the decision regions are described in subsection (1) through (7).

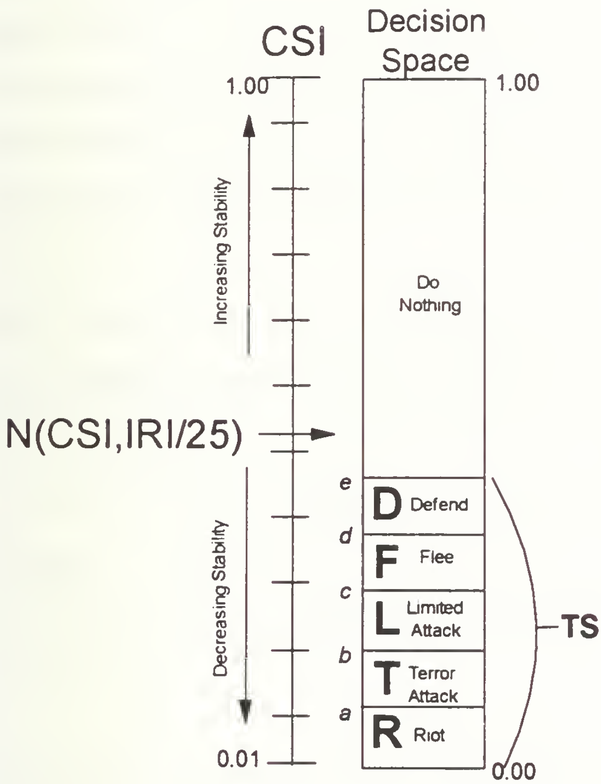



Figure 4. Civil Decision Space Definitions.

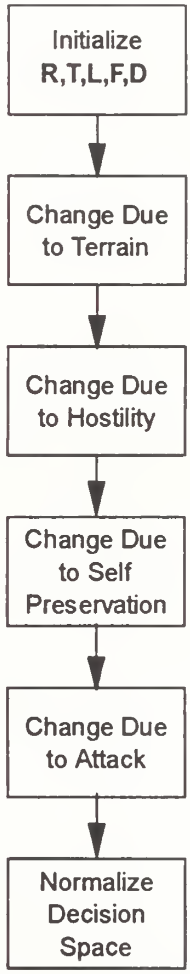



Figure 5. Civil Decision Model.

(1) Initialization. At the beginning of each decision cycle, the decision space is reinitialized. Regions **R,T,L,F,** and **D** are initialized at 0.08 each. The Total Space (TS) is initialized at 0.40. The constant 0.08 is simply a one- fifth share of the TS. The initial value of 0.40 is an estimate that is chosen to give each alternative a positive probability in the decision space, while initially setting the option of "Do Nothing" as the most probable option. Other initial values for the TS would be equally valid

Rationale: This initialization creates a total probability, TS, that the civilian unit will do something with a probability of 0.40 and a probability of 0.60 of doing nothing. Without further information, the probability of taking any action is equal to any other action. The sizes of the decision spaces will change before the decision is made, according to the rules in sections (2) though (7) below. The 0.40 threshold also ensures that, under conditions of neutral values in opponent desire indices, the civilian unit is most likely to chose to do nothing.

(2) Terrain. This section determines the changes in the decision space resulting from the desire of the player to hold terrain, as described by the variable HG. The new values of **F** and **D** are determined by

$$\begin{aligned} \boldsymbol{F}_{New} &= \boldsymbol{F}_{Old}\left(\frac{6 - \text{Hold Terrain Index}}{3}\right) \\ \boldsymbol{D}_{New} &= \boldsymbol{D}_{Old}\left(\frac{3}{6 - \text{Hold Terrain Index}}\right). \end{aligned} \qquad (2)$$

Rationale: The only factors that a player's desire to hold terrain influences are the probabilities that the player will flee or defend. Therefore, only regions **F** and **D** are affected by the above equations. The probability of flight decreases as the desire to hold terrain increases. In a similar manner, the probability of defending increases as the desire to hold terrain increases. The constant values of three and six shown in the equations are chosen to cause a neutral value for the Hold Terrain Index to

result in no change to the previous values of **F** and **D** and for other changes to be made in proportion to their deviation from the neutral value of 3.0.

(3) Hostility. This section describes the changes in the decision space based on the hostility index of the civilian unit against the closest opponent player, within one node distance. If more than one opponent is within one node distance, then the largest hostility index will be used. In equation (3) the total space, TS, indicates the total probability of possible action, not including "Do Nothing". This space is not the simple summation of **R,T,L,F,** and **D** regions. Its importance will become apparent in the normalization step. The TS will be reinitialized to the initial value at the beginning of each decision cycle to keep future decisions from being dominated by consideration of past decisions,

$$TS_{New} = \frac{(TS_{Old})(Hostility\ Index)}{3}. \tag{3}$$

Rationale: The hostility of the player against any nearby opponent determines the size of the probability region in which a civilian unit will choose one of the actions listed in the decision regions. The total size of all "do something" regions increases from the initial state of 0.40 when hostility is above three (neutral) and decreases when the local opponents are relatively friendly. Since $\mathbf{TS}_{old}$ is initialized at 0.40 and HI is in the range of one to five, the new value of **TS** will necessarily be between 0.133 and 0.667.

(4) Self preservation. The player's desire for self preservation changes the decision space as shown in equation set (4). FR is the force ratio of all opponents' perceived combat power over all friendly units' combat power within the same node and up to one node away. For purposes of this equation, FR is bounded by the lower value of 1/3 and an upper bound of four. Values outside this range cause unsatisfactory results. SPI is the Self-Preservation Index for the civilian unit player. **R**, **T**, **L** and **F** are the old and new sizes of the respective decision regions,

$$
\begin{aligned}
R_{New} &= R_{Old}\left(\frac{3}{SPI}\right)\left(\frac{2}{FR}\right)\\
L_{New} &= L_{Old}\left(\frac{3}{SPI}\right)\left(\frac{2}{FR}\right)\\
T_{New} &= T_{Old}\left(\frac{3}{SPI}\right)\left(\frac{2}{FR}\right)\\
F_{New} &= F_{Old}\left(\frac{SPI}{3}\right)\left(\frac{FR}{2}\right).
\end{aligned}
\tag{4}
$$

Rationale: Equation set (4) accounts for a player's desire for self preservation balanced against the relative combat power of opponents. A strong desire for self preservation alone will not force a player to action, especially against a perceived weak opponent. This equation uses the unique capability of FTLM which relies on the perception data base to determine relative force ratios. Under these equations, a strong desire for self preservation, coupled with a high force ratio, will increase the probability of the civilian unit selecting to flee, and decrease the probability of engaging in limited combat, performing a terrorist act, and rioting. The fixed value of two in the equation accounts for a rough "break even" point for force ratios to compel action from a civilian unit. The constant three in the equations is the neutral point for the scale of SPI, where SPI is on a scale of one to five.

(5) Probability of attack. This section describes the impact on the decision space by the perceived probability of attack from an opponent. This calculation is a three-stage process. First, the probability of attack is calculated in three steps as shown in

$$
\begin{aligned}
&Step1:\ Pa1 = 0.1HI + ((1 - 0.1HI)(.9ATNG))\\
&Step2:\ Pa2 = Pa1 + 0.3(1-Pa1)(Mv)\\
&Step3:\ Pa = Pa2 + (Ca - 0.3)(1 - Pa2).
\end{aligned}
\tag{5}
$$

Pa is the probability of being attacked, according to the perception of the unit that is in the decision cycle. Pa1 and Pa2 are the results of intermediate steps in the calculation that are carried forward to subsequent steps. The attacker is the most hostile player unit

within one-node distance. ATNG is a Boolean parameter of the model that is equal to zero if player N has never engaged in direct combat against player G during the model run life. This parameter changes to one the first time player N is in combat with player G. A value of one can be set as an initial condition in the model but will not change back during model play. HI is the hostility index of the most hostile player against the player in the decision cycle. Mv is another Boolean variable whose value is one if the most hostile player has moved a unit within a one-node distance of the decision unit within the past day and is zero if that player has not moved a unit within an adjacent node. Ca is the percent of combat arms personnel in the hostile player's force within one-node distance and is calculated by

$$Ca = \frac{\dfrac{\Sigma\ (Tanks+APCs)}{\Sigma\ (Trucks+Tanks+APCs)} + \dfrac{\Sigma\ (Armed\ Personnel)}{\Sigma\ (All\ Personnel)}}{2} . \qquad \textbf{(6)}$$

If the resulting Pa is negative, then Pa is set to zero. A numerical example of these calculations follows the equations sets.

Rationale for equation set (5): Step 1 changes the probability of perceived attack based on the hostility index of the most hostile enemy player-unit within the one-node limited field of vision of the civilian unit. The hostility index is the starting point for this calculation. Depending on the value of HI, the initial probability will be in the range of 0.1 to 0.5. This indicates that hostility alone is not sufficient for a player to conclude that he is likely to be attacked. The addition of ATNG in step one modifies the initial state to include the memory of the perceiving unit with regard to the combat history he has with that most-hostile opposing player within one-node distance. A player who has attacked before and has a high HI would result in a maximum Pa1 of 0.95, while a player who has not attacked before and has a low HI would result in a minimum Pa1 of 0.1. Step two begins with the result of step one as an initial state and adds 0.3 of the unused decision area if that most hostile unit has moved within the past day. This would indicate that a moving unit is perceived as a greater threat than a stationary unit. This modification can change the range of the decision state to 0.1 to 0.965, depending on the

variables that have been used to this point. The final step in the calculation, accounts for the perception of the civilian unit of the combatant versus non-combatant capability of the opponent unit. The civilian unit would not perceive a threat from the approach of a perceived convoy of trucks having a small percentage of combat personnel. The rationale for the Ca calculation is presented later. The constant 0.3 is subtracted from Ca to represent a threshold level of percent combat forces that would be perceived to be threatening. This final step results in a range for Pa of -0.17 to 0.9895. Negative values are interpreted as zero.

Rationale for equation (6): This equation averages the ratios of numbers of combat vehicles with the ratio of combat personnel. The equation implies that the combat power of a vehicle is equal to that of an armed person. It is recognized that the equation will be most accurate for units consisting mostly of personnel or vehicles but will have a less valid, but useful, linear relationship for units with mixed compositions. This calculation is not used for any attrition or decision calculations elsewhere in the model so its effect is limited to this decision space use.

Now that Pa and Ca are calculated, changes to decision spaces **D** and **F** are calculated using

$$\begin{aligned} \boldsymbol{D}_{New} &= \boldsymbol{D}_{Old}(Pa)\left(\frac{4}{FR}\right) \\ \boldsymbol{F}_{New} &= \boldsymbol{F}_{Old}(FR)(Pa)\,. \end{aligned} \tag{7}$$

Rationale: Without regard to other possible events, populations are more likely to flee from an area if they perceive they may be attacked by a superior force. Further, knowing that they may be attacked, they are more likely to defend if they believe they can win. The constant four is used to double the size of Pa so that an initial neutral value of 0.5 will be converted to a neutral multiple of one. The remaining two in the constant accounts for the neutral threshold of force ratio that the civilian unit perceives as threatening. Since this force ratio is based on perceived enemy combat power, it may not represent the actual force ratios present. Future model developments may use this feature to model deception operations.

(6) Normalization. This step ensures that the entire decision space remains equal to one and that the decision regions maintain their relative sizes. This step also ensures that the option "Do Nothing" remains possible. Finally, this step sets the values of *a,b,c,d* and *e*, based on the sizes of the decision regions. The values of *a,b,c,d* and *e* are the threshold levels that actually determine the choice of the civilian unit. The decision space is normalized using

$$
\begin{aligned}
R_{Norm} &= \frac{R_{Old} * TS}{R+T+L+F+D} \\
T_{Norm} &= \frac{T_{Old} * TS}{R+T+L+F+D} \\
L_{Norm} &= \frac{L_{Old} * TS}{R+T+L+F+D} \\
F_{Norm} &= \frac{F_{Old} * TS}{R+T+L+F+D} \\
D_{Norm} &= \frac{D_{Old} * TS}{R+T+L+F+D},
\end{aligned}
\tag{8}
$$

and the values of the *a,b,c,d,* and *e*, which will be used for the action selection in subsection (7) are:

$$
\begin{aligned}
e &= 1 - TS \\
d &= e + D_{Norm} \\
c &= d + F_{Norm} \\
b &= c + L_{Norm} \\
a &= b + T_{Norm}.
\end{aligned}
\tag{9}
$$

Rationale: This step ensures that the model produces probabilities within the range zero to one. Probability expressions outside that range are not admissible.

(7) Mission selection. Once the decision space has been defined by the above equations, the unit selects an action. To select an action, a random number is drawn from a normal distribution with parameters (CSI, (IRI/25)), within the limits of zero and one. Once the number is chosen, the following algorithm is used to select an action.

```
N:= Normal(CSI,0.5);
IF N > a Then RIOT;
ELSEIF N <= a AND N > b Then Terrorist Attack;
ELSEIF N <= b AND N > c Then Limited Attack;
ELSEIF N <= c AND N > d Then FLEE;
ELSEIF N <= d AND N > e Then DEFEND;
ELSEIF N <= e Then Do Nothing;
```

Rationale: A normal distribution is used to weight the probability of selection around the CSI. The limits of zero and one ensure that randomly drawn values will remain within the decision space. The variance parameter for the normal distribution will have values in the range of 1/25 to 5/25 depending on the value of the attribute of IRI in the model. At the higher end, this will place 50 percent of the probability curve within +/- 0.50 of the CSI value.

The normal curve is used here because its parameters are well-understood and easily calculated. The normal curve has a disadvantage in that the tails of the curve, which fall outside the zero to one boundaries, are lost. Knowing that, the programmer must establish an arbitrary rule to account for the lost area under the curve. The Beta distribution is a possible alternative to the normal distribution. The Beta distribution is already limited within zero and one. The translation of the shape parameters of CSI and IRI into $\alpha$ and $\beta$ for the Beta distribution would be required for its implementation. [Ref. 7]

*b. Riot model.*

This paragraph describes the actions of units that have chosen to riot. Rioting is undirected violence that causes disruption of productivity, slower movement rates and small amounts of attrition. The requirements of the rioting submodel are to determine the duration and intensity of the riot. Figure 6 shows the basic flow of the Riot Model. It indicates that if riot is chosen, the rioting takes place in, at most, one day increments. The attrition, therefore, can be aggregated over an entire day. When the duration is less than one day, the attrition is pro-rated for that part of the day that is spent in rioting. Intensity is determined by

$$Intensity = \frac{\frac{HI}{5} + (1 - CSI)}{2} + N(0, 0.15) \tag{10}$$

and duration by

$$\begin{aligned} R_0 - (aN)(t)(CSI) &= R_{BP} \\ R_0 - (aN)(t)(CSI) &= 0.85R_0 \\ -aN(t)(CSI) &= -0.15R_0 \\ Duration = t &= \frac{0.15R_0}{(aN)(CSI)}. \end{aligned} \tag{11}$$

In equation (11), $R_{bp}$ is the breakpoint of the rioters, which is arbitrarily set at 0.85 of the initial number of rioters. $R_o$ is the number of initial rioters which is the number of unarmed personnel in a node that are rioting. N is the armed personnel strength of all units, regardless of player, in the node that are defending or doing nothing. When an individual rioter is forced to cease rioting, either because he has been injured by police or military action, or because he has been arrested, or because he developed a new fear of arrest or injury, that rioter is considered to be overcome. The parameter *a* is the rate at which anti-rioters overcome rioters. For purposes of this model, the value of *a* is set at four. Equation set (11) is based on the relation that the number of rioters, minus the rate they are overcome over time, equals some remaining number. If that

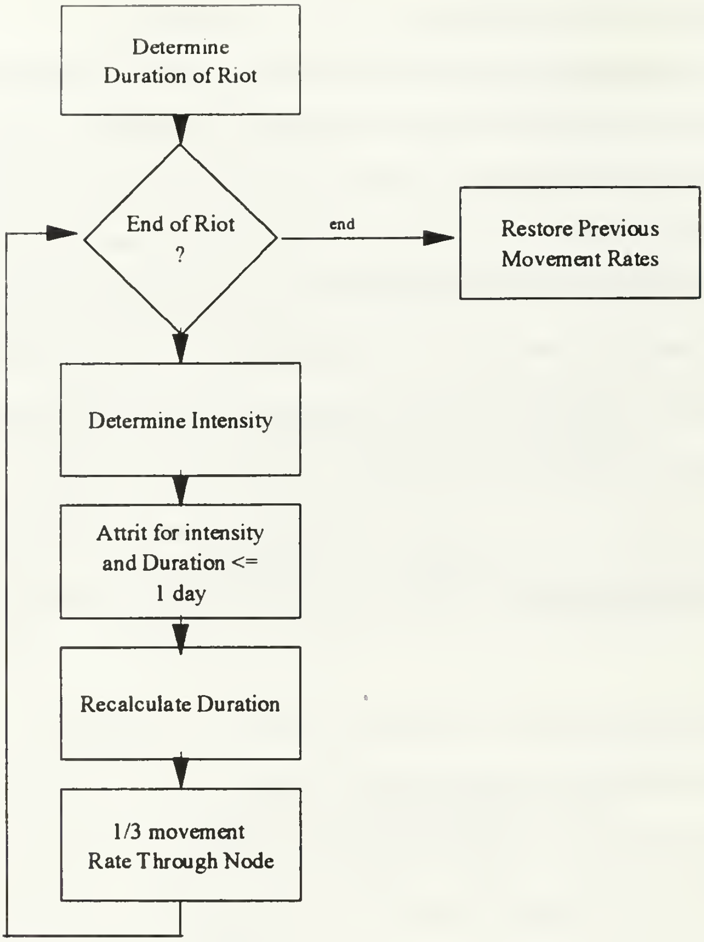



Figure 6. Riot Model.

remaining number is set to a rioter breakpoint, the resulting equation can be solved for the time at which that breakpoint is reached.

In the intensity equation (11), HI is the highest hostility index of the rioting unit against any other player unit in the same node. Attrition is calculated by

$$Attrition = (Intensity)(t)(population)(\delta) . \qquad \textbf{(12)}$$

The attrition equation (12) is a function of the intensity and duration equations, the unit population, and the attrition coefficient, δ. The result of the intensity equation is a random variable bounded by a lower limit of zero. The result of the duration equation is also a random variable based on the ability of other units to put down the rioters.

Rationale: Rioting occurs in one-day increments because rioters may become fatigued daily, in the early morning hours. Logically, rioting activity slows between the hours of 2 and 10 AM and reignites on the following day. The hours of inactivity are not important except to show a daily cycle for rioting activity.

The intensity equation averages the values of civil instability , (1.0 - CSI), and the hostility index. HI is divided by five to convert it to a ratio scale.

Based on historical precedent of the Los Angeles riots, the upper limit of the coefficient of attrition should be in the neighborhood of 0.00075. A numerical example with HI = 4 and CSI = 0.25 for one day of rioting yields an expected attrition of one death per thousand rioters. These figures approximate the 58 deaths that occurred over 10 days of rioting in Los Angeles.[Ref. 8] This particular historical precedent may be inappropriate since rioters in L.A. exhibited undirected violence, targeting primarily their own neighborhood and neighbors. Rioting, as an act of a player in a theater of warfare, should be directed against another player's forces or assets. Rioting data from the Republic of South Korea are probably more characteristic of OOTW rioting than the example used here.

#### c. *Terrorist attack model.*

The Terrorist Attack Model is based on two key decisions: selection of a target and calculation of attrition. Selection of a target is made in a manner similar to the Civil Decision Model. The decision space is composed of all of the units on the same node as the attacking unit, excluding units from the same player as the attacking unit.

The decision space is initialized with each possible target unit as a decision region with size 1/n, where n is the total number of units found in the node. Then the decision regions are modified by

$$
\begin{array}{ll}
\textit{Step 1:} & \textit{Multiply each region by } \frac{HI}{3} \\
\textit{Step 2:} & \textit{If unit is defending divide by } 2 \\
\textit{Step 3:} & \textit{Normalize decision space} \\
\textit{Step 4:} & \textit{Compare } U_1[0,1],
\end{array} \tag{13}
$$

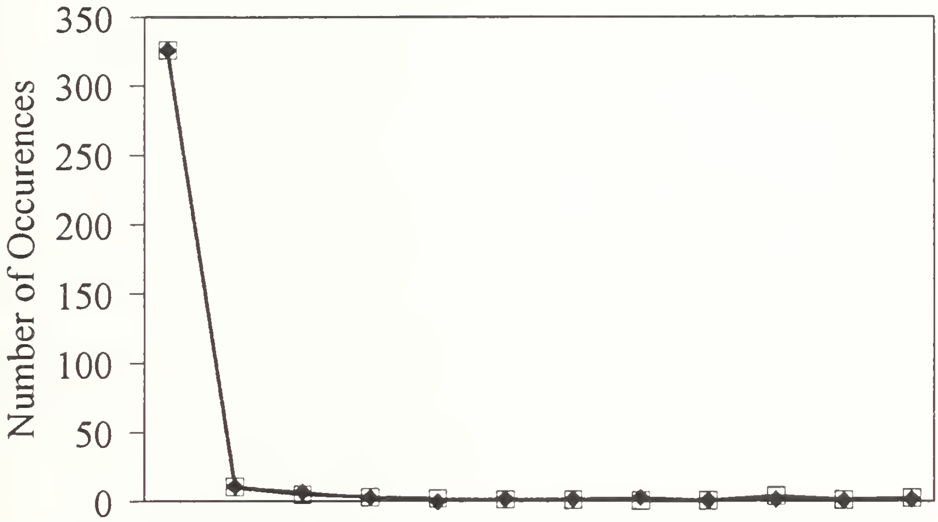
to change the probabilities of each being chosen. Finally, the model selects a random number from a uniform distribution with parameters (0,1). The selection of the target unit is based on the region determined by the random number draw. In equation set (13), HI is the hostility index of the attacker against the potential unit. Units from the same player are assumed to have a HI of one against each other.

Once the target unit is selected, the attrition against that target is determined. According to many sources, terrorism seldom produces casualties [References 9,10,and 11]. When casualties are produced, the number of casualties is usually small. Incidents of mass casualties (over 30) are rare in history, occurring only 37 times in the past 40 years. According to statistics, only 15 to 20 percent of all terrorist incidents involve fatalities; and of those, two-thirds involve only one death [Ref. 11]. The historical data of casualties per incident is fitted to a Weibull distribution with parameters $\lambda = 2.3597$ and $p = 0.2324$. Figure 7 shows the curve fit of the historical data compared to the expected distribution drawn from the Weibull distribution. The resulting attrition is determined in

$$
\begin{array}{c}
\textit{Attrition} = \textit{MIN}(\sim \textit{Weibull}(\lambda = 2.3597, p = 0.2324), \textit{Personnel}) \\
\textit{If } U_2[0,1] < \alpha \textit{ then} \\
\textit{Attrition} = U_3[0,1] \times (\textit{Personnel}).
\end{array} \tag{14}
$$

The attrition in equatuion (14) is the number of casualties produced in the target unit, limited by the number of personnel in the unit. Then a second uniform random number is drawn to determine if severe casualties are incurred. There is a small probability ($\alpha$) that severe casualties will result from a terrorist attack. For this example, that probability is set at 0.002. While that probability is so small that it normally would be accepted as a zero probability, we have seen in recent history that such incidents of high casualties

do happen and are very significant politically. In the event of severe casualties, the number of casualties is based on a uniform distribution over the range of personnel present in the target unit instead of the Weibull random number. [Ref. 12 ]




| Numbers of Casualties | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9-19 | 20-29 | 30+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observed | 326.00 | 11.00 | 7.00 | 3.00 | 0.00 | 2.00 | 2.00 | 3.00 | 1.00 | 2.00 | 1.00 | 2.00 |
| Expected Weibull | 326.00 | 10.60 | 5.10 | 3.20 | 2.10 | 1.60 | 1.30 | 0.93 | 0.81 | 4.16 | 1.40 | 2.80 |

Figure 7. Casualties Per Terrorist Incident.

Rationale: The parameters of the terror attack attrition equation are determined from historical precedents. The highest numbers of casualties in recent terrorist attacks have been the bombing of a Pan Am aircraft over Lockerby Scotland (189 Killed), and the terrorist attack on the U.S. Marine barracks in Beirut, Lebanon (264 killed). Other terrorist attacks produced significantly fewer casualties. Historical records of 700 terrorist incidents in 1990-91 show that terrorist incidents rarely cause injury and deaths are more rare. High casualty incidents (over 10 killed and injured) occur in fewer than 1 in 500 incidents. The probability of defending units being chosen as targets is lower because they are assumed to be alert and taking active measures to deter terrorism. Terrorist teams would see them as a more difficult target and therefore be less likely to

select them. It should be noted that the data for this submodel refer to U.S. citizens, businesses, and activities as the targets during a period when no terrorist organization was actively working against U.S. interests in an OOTW environment. A more likely estimate of terrorist casualties in a combat theater might be derived from the experiences of the United Kingdom in Northern Ireland, or Israel experiences in the Gaza strip and West Bank areas.

*d. Limited combat model.*

The limited combat model is based on the premise that, in OOTW, battles of annihilation are rare. Limited combat is more likely; units decide to attack a weak opponent unit to cause enemy deaths or to seize its assets. Limited combat does not take place with the intention to seize and hold terrain. Recent examples of limited combat are mortar attacks on the U.S. compound in Mogudishu, Somalia, and artillery duels in the former Yugoslavia. The key elements of this model are determining the duration of the combat and calculating attrition. The limited combat model is depicted in figure 8.

The duration of combat is determined by

$$Duration = \frac{1}{\sqrt{ab}} \ln\left( \frac{Y_{bp} - \sqrt{Y_{bp}^2 - Y_0^2 + \frac{b}{a}X_0^2}}{Y_0 - \sqrt{\frac{b}{a}}X_0} \right) + N(0, 0.5). \qquad \textbf{(15)}$$

$Y_0$ is the initial strength of the attacker, and $Y_{bp}$ is the breakpoint of the attacker. The parameters $a$ and $b$ are the rates at which the attacker and defender attrit each other. $X_0$ is the initial strength of the defender [Ref. 13 ]. The significant difference is that the attacker's breakpoint is earlier than that used for a deliberate attack. The earlier breakpoint shows the attacker's lower threshold for accepting losses to gain a limited objective.

Rationale: The breakpoint for the attacker is set at a high level, because the attacker's intention is to inflict harm on the enemy with minimal losses to himself. An attacker would want to break contact early if the battle is not going in its favor. A breakpoint of 0.85 or 0.9 of the attacker's initial strength is proposed for this equation.

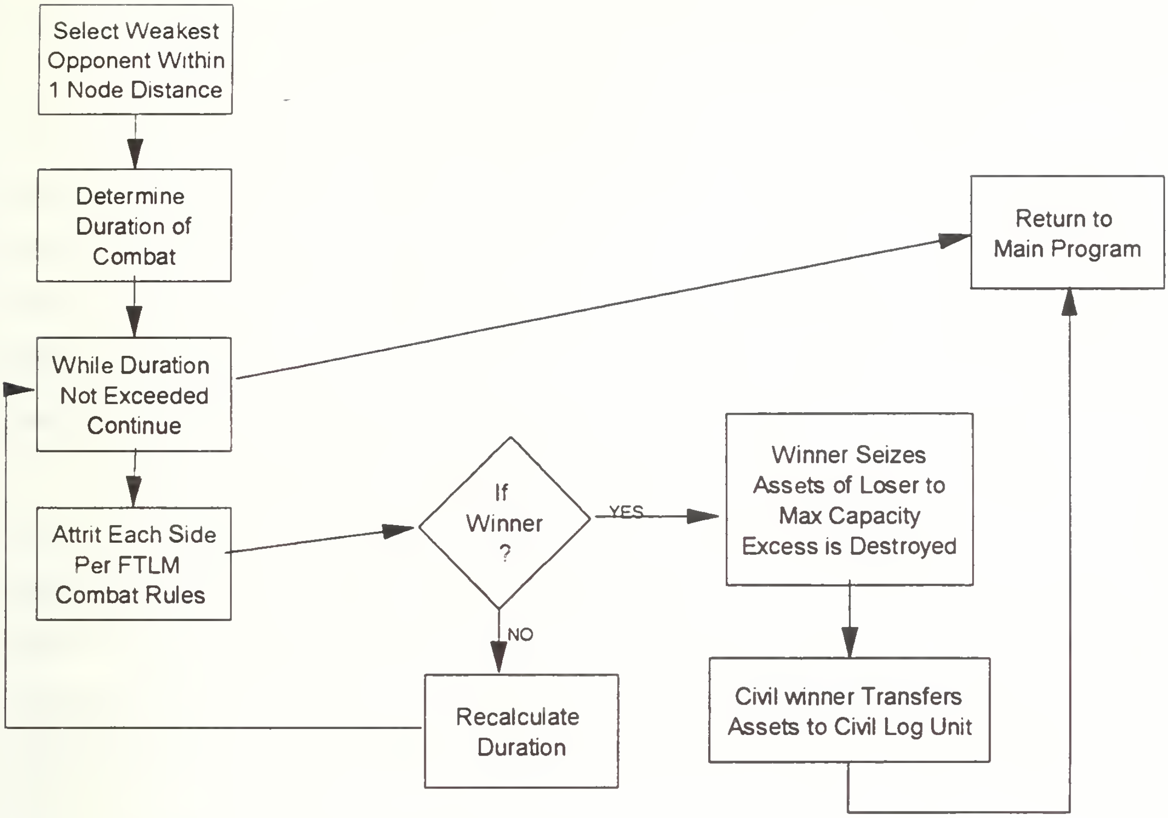



Figure 8. Limited Combat Model.

*e. Flight model.*

Flight is the option chosen by a ground unit when it fears destruction and cannot fight. The flight model has one key decision to represent: in which direction to flee. The options include any adjacent node. To decide direction, the fleeing unit takes a hostility inventory of the nodes around it. Each node is assigned a number, RR, as determined by

$$RR = \sum_{units}^{all} (Perceived\ Combat\ Power)(HI-3). \qquad (16)$$

The node with the smallest number determines the direction of flight.

Along with deciding a new direction, the model increases the carrying capacity of the fleeing unit. It is suggested that the new capacity be approximately 1.25

times the old capacity. The rest of the move is accomplished according to the FTLM core model.

Rationale: Having already chosen to flee, the unit's choice of direction will be based on the perceived relative safety of the proposed new direction. To determine this, the fleeing unit goes in the direction which they believe is occupied by friends. Its carrying capacity is increased to portray the fact that vehicles will be overloaded to save whatever property that can be carried from enemy capture. The constant value, three, converts a neutral value of Hostility Index to zero and friendly forces to negative values. This ensures that a strong friendly force will be chosen over a weak enemy force.

#### *f. Defense model.*

Defending civilian units are taking actions within their node to increase their survivability in the event of hostility. To accomplish this, the defending unit has three additional characteristics: their production will drop to one-third of normal, their consumption of "other" supplies will double, and their chance of being surprised will be reduced.

Rationale: Defending units are using their stored "other" supplies to erect barriers and harden structures against attack. The population's able-bodied men are guarding their homes, boarding up windows, hoarding supplies for personal use, and conducting reconnaissance instead of producing. Finally, because defenders are alert and preparing for enemy action, they will be less likely to be surprised than will a "do nothing" unit.

#### *g. Movement model.*

Moving is the action taken by a unit to change locations from one physical node to another. FTLM already has sufficient movement parameters for most cases. A case that is unique to OOTWTLM is the action taken by civilian units. When a civilian unit chooses limited attack or terror attack, and no other player is on the same node, the attacking unit must move to another node that has a suitable target unit. The attacking unit will only consider the units in adjacent nodes for possible attacks, because they were already considered in the decision to attack.

*h.* *Support model.*

Support in the model exists only as a scripted function of the U.S. player.

**5. Attrition by starvation and disease.**

Although the formula for attrition due to starvation was devised to determine civilian casualties in the Somalia scenario, it should be applied to all of the units in the model. In most cases, a military force will be supplied with enough food to satisfy its own needs. In some extreme cases, like the defense of the Philippines in WWII, military units are subject to starvation and disease like civilian units.

The basic formula for determining attrition due to starvation is a Lanchester style equation. In starvation models, the attrition coefficient is variable with time. The longer a population is under famine conditions, the faster they will be attrited. Additionally, as the famine progresses, diseases that result from the famine will cause more casualties than starvation [Ref 6]. According to information in [Ref 6], it is reasonable to assume that deaths due to disease will be 1.3 times the number of deaths due to starvation, over time. The general equation is then

$$Attrition = ROUND(2.3(Population)(KS)), \tag{17}$$

where KS is the percent killed by starvation and is a random number drawn from a normal distribution according to

$$KS = \sim N\left(1-e^{-\beta},\ \frac{1}{12}(1-e^{-\beta})\right). \tag{18}$$

The function *ROUND* rounds the resulting attrition to the nearest whole number. KS is bounded by zero and one to preclude negative numbers and killing more people than are present. $\beta$ in equation (18) is based on the ten day starvation history of the unit by

$$\beta = \sum_{i=1}^{10} (X_i)(\gamma_i). \tag{19}$$

In equation (19), $X_i$ is the percent of people who have been without food for i consecutive days, and $\gamma_i$ is the attrition coefficient for i days of starvation as found in Table 5. The constant 2.3 in equation (17) accounts for attrition by disease added to attrition by starvation. The values found in Table 5 are based on a simple algebraic progression and are not data supported.

| i | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $\gamma$ | .0001 | .0002 | .0004 | .0008 | .0016 | .0032 | .0064 | .0128 | .0256 | .0512 |

Table 5. Starvation Attrition Coefficients.

For these equations to work, the following assumptions are necessary:

- If the population group has insufficient food to meet its daily consumption needs, over time, the same segment of the population will be denied satisfaction.

- A normal population has sufficient weak and strong people to account for attrition in the first days of starvation and survivors after many days of starvation.

- After ten days of starvation the attrition rate peaks. Although a higher attrition rate is expected as the famine continues, there is already a higher than expected attrition early in the famine cycle. This is done for computational simplicity. A longer than ten day cycle could be used, if desirable. This length was sufficient to demonstrate the characteristics of the attrition model.

### 6. Attrition due to collateral effects of combat.

#### *a. Discussion of methodology: heuristic versus algebraic.*

The calculation of collateral damage presents some unique problems in FTLM. The theater-level nature of the model tends to looks at nodes as homogeneous areas. In the case of OOTWTLM, each node may contain units from several players. Further, because each node may have sizes of several kilometers, both long-range and close combat effects can be expected in a single node. Commonly, attrition is calculated

using a variety of techniques such as Lanchester equations, cookie cutter, and confetti algorithms [Ref. 13]. Some high resolution models, like JANUS, calculate the trajectory and effect of each round based on P(hit), P(kill), and damage radius circles. Lower resolution models, like FTLM, rely on algebraic approximations to aggregate results over large units. The algebraic solutions depend on attrition coefficients derived from historical data curve fitting and from data produced by high resolution models.

While the algebraic solutions are useful, their validity depends upon the availability and validity of appropriate coefficients of attrition. When appropriate coefficients are not available, estimates must be used.

Since no historical data exist to curve fit OOTW calculations, and no high resolution model exists to generate such data, a solution that uses an analytical/mathematical approach is achieved by using estimates for the attrition coefficients. With such limited tools and historical data in the area of OOTW, the validity of any such estimates would be suspect. Appendix B describes an analytical approach to partitioning attrition between target and non-target units.

Heuristic solutions bridge the gap between having no solution and having analytical solutions based on estimates. Heuristic solutions have the advantage of being computationally simpler while producing solutions that approximate algebraic solutions over a limited range. The rest of this section describes a heuristic approach to determining attrition caused by collateral effects of combat.

#### *b. Elements of collateral damage calculations.*

A complete model for determining collateral damage, in terms of personnel attrition, should include these elements:

- Area of non-target unit in target area.
- Area of target unit in target area.
- Density of non-target unit in target area.

- Firepower delivered into target area as a function of the strength of the firing unit.
- Defensive posture of non-target unit.
- Capability of firing unit to discriminate between target and non-target units and sub-elements of units.

Most of the above listed elements are represented in Lanchester's square law attrition equations that are already used as an option in FTLM to compute combat casualties. The significantly missing element is the ability of the firer to discriminate between targets and non-targets. The discrimination ability is a function of sensor quality, intelligence fusion quality, and some measure of the visual distinction between targets and non-targets. The last element is especially important in OOTW operations where hostile armed forces and civilian populations are visually indistinguishable, coming from a common ethnic stock and having no uniform. Determining a quantification for visual distinctions has not been developed in time for inclusion in this document. As a temporary measure, the heuristic approach in the next section is proposed.

#### c. *The heuristic model.*

Attrition due to collateral effects of combat occur in three cases:

- Area fire weapons effects against non-targets.
- Aimed fire weapons effects against non-targets.
- Aimed and area weapons effects against non-target units from the same player as the firing unit.

In the first case, the attrition coefficient of non-target units, in the same node as target units, is 0.3 of the attrition coefficient for the target unit. This attrition coefficient is used in the common Lanchester square law equation that is already included in FTLM. This applies to all area fire weapons effects. Area fire weapons include all

air delivered munitions, including "smart" bombs, high explosive tank rounds, artillery and mortar fire.

Rationale: The effects of area fire weapons cause damage to units in the same area as the target. The target receives more damage because area fire weapons have some capability to be directed at a particular target. This accounts for the indiscriminate way in which large amounts of high explosive kills targets without regard to nationality.

In the second case, aimed fire weapons cause collateral attrition with an attrition coefficient of 0.1 of the coefficient for the target unit.

Rationale: The aimed fire kill rate is lower against non-target units in target nodes, but they still sustain some damage because of their proximity to the target. This effect also accounts for failure by the firing unit to correctly distinguish between targets and non-targets in the same node. This case specifically addresses the firing unit and the non-firing unit not being from the same player.

The last case is collateral damage to units from the same player as the firing unit. Their attrition coefficient is 0.01 of the attrition coefficient of the target unit.

Rationale: Since the firer presumably has better communication and control measures within his own unit, the attrition rate is substantially less. While this does show some fratricide play, that is not its intent. This case only applies to the friendly units that occupy the same node as the target unit and, in effect, are receiving "spillover" of the fire directed primarily at the legitimate target.

### 7. **Logistics considerations of civilians.**

Modeling civilians raises some unique logistic considerations. Civilians produce as well as consume. Urban units can produce manufactures goods, such as ammunition, and civilian units in rural areas produce food in agriculture and bulk processing. Since OOTW missions often include delivering food to civilian units, the logistic model must have the ability to transfer assets from one unit to another. Finally, in some cases, the model must handle assets that are not owned by any player. The following paragraphs detail methods for modeling each of these problems.

### *a. Transfer of assets.*

Transfer of assets should occur under three circumstances: seizure following combat, resupply from a same player unit, and delivery to civilian units as a result of mission completion.

In the first case, transfer of assets should occur automatically at the end of combat, or limited combat. The assets of the loser are transferred to the winner, up to the capacity of the winner to carry.

In the second case, theater resupply of log units can be handled by giving the log unit a production rate of the supplies it would receive from outside the theater. If the transfer of goods into the theater is an important aspect of the model, the modeler can create an offshore log unit at a dummy node. The offshore unit would have a production rate and use transportation units to move the assets to shore log units. Otherwise, units should have assigned relationships for receiving support from log units. If the units occupy the same node, they can transfer assets up to the capacity of the receiving unit.

Finally, U.S. units need the capacity to deliver assets to civilian units in order to accomplish a humanitarian mission. This is done by units that have mobility and the capacity to move the desired assets to the same node that contains the receiving unit. The transfer takes place after the unit arrives.

### *b. Assets that are not owned.*

In some cases, assets will be abandoned on the terrain without an owning unit. This will happen most often when a unit defeats a log unit in a limited attack and seizes the log unit's assets. The attacking unit may not have the capacity to carry all of the assets of the log unit. Whatever is left behind should be assigned to a dummy unit that appears at that time, has a hostility index of one against all players, and has only one unarmed person. This would allow any other player in the game to seize these abandoned assets with a minimum of effort at any point in the game.

c. *Production.*

As has been discussed previously, civilian units have production rates for each asset type. These rates are set as an initial condition for each unit. Military units do not have production rates, except for the case described in the previous section.

Each action of a civilian unit, except for "Do Nothing", modifies the unit's ability to produce. Table 6 shows the modifiers to production for each type of action. To determine the modified rate of production, the modifier is multiplied by the normal production rate. The *IN* in the Modifier column of Table 6 refers to the intensity of the rioting, as calculated in equation (10).

| Modifier | Activity |
|---|---|
| 0.75(1-IN) | Riot |
| 0.65 | Terrorist Attack |
| % Armed | Limited Attack |
| 0.0 | Flee |
| 0.35 | Defend |

Table 6. Production Modifiers.

Rationale: The modifiers shown in Table 6 are estimates. Other estimates may be used if there is sufficient rationale. The rate modifier for Riot is a function of the intensity of riot as calculated in the riot submodel. As rioting becomes more intense, less civilian occupation occurs, resulting in lower production. The modifier due to terror attack is a result of reaction by police, fire, civilian , and military authorities to the attack. In some areas, martial law can be imposed, limiting the productivity of civilians. A small part of this modifier is also the lost productivity of the personnel who participated in the attack and who were targeted by the attack. The modifier for limited attack is based on the lost productivity of the armed personnel in the unit who are participating in an attack instead of producing. During flight of a unit, no production will be possible. Finally, the modifier for defense accounts for lost productivity because able-bodied men will be engaged in non-production activities such as neighborhood watch, prisoner guard, erecting

barriers, stockpiling supplies, and attending local civil defense training. This assumes that some people will continue to produce assets during the defense.

### 8. Non-Government Organizations (NGOs).

NGOs are international or local relief organizations, such as the Red Cross and Catholic Relief Organizations. These agencies are characterized by having special capabilities that are used to improve the conditions of the theater.

Although they are technically independent of other player control, inasmuch as their goals parallel another player's goals, NGOs can be modeled as logistics units of that player. Care should be taken to ensure that they are not designated as combat units, since they are usually unarmed and their cooperation with player forces is limited to their own charter as a relief organization. An NGO that is particularly friendly with an opposition player should be modeled as a log unit of that player. NGOs that are particularly independent and uncooperative can even be modeled as separate players.

The key to making this decision is the question, "is the independent action of the organization a significant element of the process being modeled?" In most cases, aggregating them into players with similar goals will suffice. Of note, NGOs in this thesis are modeled as two units per node. One unit is a logistic unit with large capacity to store assets, but with no capacity to transport assets. The second is a transportation unit that can move assets from the log unit to where they are needed. The transportation units have small capacities to store assets. All NGOs have been modeled as subunits of the U.S. player.

# IV. NUMERICAL EXAMPLE.

## A. INTRODUCTION.

This chapter provides a numerical example of the procedures described in Chapter III. The numerical example uses an abbreviated scenario as described below to demonstrate many of the essential model characteristics. The calculations and tables produced here focus on the model features that were described in Chapter III. No attention is given to FTLM model details that were already documented in [Ref. 3].

## B. SCENARIO.

This scenario is based on Operation RESTORE HOPE. For simplicity, it uses a very limited scale and scope, as described below.

### 1. Troops.

Table 7 shows the forces used in this limited scenario. A total of seven units is used to represent three players. The four units that represent civilian population units demonstrate various states of starvation, hostility to the BLUE player, and military strength. Table 8 shows the unit starvation profiles for each unit. Table 9 shows the initial conditions that apply to each player.

| Player | Unit # | Unit Type | Init Node | # Armed Personnel | #unarmed Personnel | Trucks | APCs |
|---|---|---|---|---|---|---|---|
| Blue | B.1 | NGO | N3 | 1 | 50 | 0 | 0 |
| Blue | B.2 | Trans | N3 | 1 | 50 | 25 | 0 |
| Blue | B.3 | Inf | N2 | 750 | 2 | 25 | 42 |
| Red | R.1 | Civ | N1 | 25 | 150 | 3 | 0 |
| Red | R.2 | Civ | N2 | 50 | 200 | 5 | 0 |
| White | W.1 | Civ | N1 | 25 | 200 | 2 | 0 |
| White | W.2 | Civ | N6 | 10 | 200 | 2 | 0 |

Table 7. Force Initial Conditions.

| | Proportion of Population Without Food for i Days | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| i→ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| B.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| R.1 | .05 | .05 | .05 | .05 | .05 | .05 | .05 | .05 | .05 | .05 |
| R.2 | .05 | .05 | .05 | .05 | .05 | .05 | .05 | .05 | .05 | .05 |
| W.1 | .15 | .15 | .15 | .15 | .15 | .15 | .15 | .15 | .15 | .15 |
| W.2 | .25 | .25 | .25 | .20 | .20 | .20 | .15 | .15 | .15 | .15 |

Table 8. Unit Starvation History.

| Player | HI | | | HG | PF | IRI |
|---|---|---|---|---|---|---|
| | vs B | vs R | vs W | | | |
| Blue | 1 | 2 | 2 | 1 | 5 | 1 |
| Red | 4 | 1 | 3 | 4 | 2 | 4 |
| White | 3 | 3 | 1 | 2 | 4 | 2 |

Table 9. Player Initial Conditions.

### 2. Terrain.

The terrain used for this model is a limited version of Figure 2, with only nodes N1, N2, N3, and N6 used. The terrain represents parts of Mogudishu and a single outlying town. Figure 9 shows the reduced terrain model. The attributes for the nodes and connecting arcs are the same as are listed in Appendix A.

### 3. Maneuver.

Maneuver of forces in the demonstration will be accomplished in three steps. The maneuver of forces portrays a truck transportation unit, located at N3, picking up supplies from a NGO depot unit, and transporting the supplies through N1 to N6. Upon arrival at N6, the transportation unit transfers the supplies to unit W.2 at N6. At the same time an infantry unit arrives at the airport and moves to N1. The three steps include the following actions:

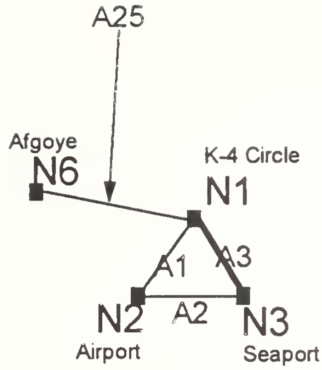



Figure 9. Limited Scale Terrain Model.

- Set initial conditions.
- Truck unit receives supplies from NGO at N2.
- Trucks move to N1.
- Trucks move to N6.
- Trucks transfer supplies to civilian unit at N1 and Infantry unit arrives at N2.
- Infantry unit moves to N1.
- End conditions.

### 4. Limitations.

This numerical example is not a full-scale or full-scope demonstration. The demonstration does not use or demonstrate actions, decisions or calculations of the core FTLM model. Instead, where those calculations are required in the demonstration, estimates are used. In many cases, the estimates that are used were chosen to specifically produce a situation that would demonstrate a OOTWTLM model attribute. Because of these limitations, possible interactions between OOTWTLM model elements and core FTLM model elements have not been fully explored. Further, where random numbers are

called for in OOTWTLM calculations, numbers were intentionally selected to show key features of the model.

## C. EXECUTION.

### 1. Step 1.

This step sets the initial conditions for the model. The initialization step includes producing initial action selections for each civilian unit and one iteration of the daily decision cycle, as described in section III.B.4.a.

#### *a. Attrition due to starvation.*

The first action is to calculate attrition due to starvation for each unit in the model. Attrition is calculated according to equations (17), (18), and (19). For example, Table 10 displays the calculations for $\beta$ for unit W.2 using equation (19). Similarly, the calculations for W.1, R.1, and R.2 are done. Table 11 shows the results of equations (17) and (18) for each of the civilian units. Since all of the Blue player units have ten-day hunger histories of zero, calculating their hunger attrition is unnecessary. Note that, while Table 11 displays a mean attrition, in number of individual deaths, the results of equation (17) would be a random number. The values in Table 11 have already been rounded.

| $X_i$ | $\gamma_i$ | $(X_i)(\gamma_i)$ | $\Sigma(X_i)(\gamma_i)$ |
|---|---|---|---|
| .25 | .0001 | .000025 | |
| .25 | .0002 | .00005 | |
| .25 | .0004 | .00010 | |
| .20 | .0008 | .00016 | |
| .20 | .0016 | .00032 | .015695 |
| .20 | .0032 | .00064 | |
| .15 | .0064 | .00096 | |
| .15 | .0128 | .00192 | |
| .15 | .0256 | .00384 | |
| .15 | .0512 | .00768 | |

Table 10. Calculation for Equation (19).

| Unit | β | KS | Population | Computed Attrition |
|---|---|---|---|---|
| R.1 | .005115 | .00510 | 175 | 2 |
| R.2 | .005115 | .00510 | 250 | 3 |
| W.1 | .015345 | .01523 | 225 | 8 |
| W.2 | .015695 | .01557 | 210 | 8 |

Table 11. Results from Equations (17) and (18) in Step 1.

### *b. Recalculation of CSI.*

Once the attrition has been calculated, the CSI for each node must be recalculated according to the modifiers in Table 3. At this point in the example, the only applicable modifiers are those due to starvation casualties. Table 12 shows the effect that casualties had on the CSI for each node. At this point in the example, large changes in the CSI are not expected. This recalculation will not have to be done again until the next simulation day which, for this example, is in step 6.

| Node | Units | Casualties | Old CSI | Modifiers | New CSI |
|---|---|---|---|---|---|
| N1 | R.1<br>W.1 | 2<br>8 | 0.45 | -0.00007x10 | 0.4493 |
| N2 | R.2 | 3 | 0.45 | -0.00007x3 | 0.4498 |
| N3 | B.1<br>B.2 | 0<br>0 | 0.45 | 0 | 0.4500 |
| N6 | W.2 | 8 | 0.40 | -0.00007x8 | 0.3994 |

Table 12. Changes to CSI Due to Starvation in Step 1.

c. ***Select civilian unit actions.***

The final part of step 1 is to select initial actions for each civilian unit from the Civil Decision Model, as described in section III.B.4.a. Since the actual selection of a civilian unit action is the result of a random number generation, the results shown in this section include the entire decision space. This section details an example of construction of the decision space for the unit W.2.

Table 13 shows each of the intermediate steps for determining the decision space. Each intermediate step is identified by the section number and equation number that describes the process. The column labeled (1) divides the decision space into five equally sized pieces. Column (2) changes the decision spaces for Flee and Defend based on the desire of the player to hold terrain.

| Changes Due to... | Initialize | Hold Terrain | Hostility | Self Preserve | Prob. of Attack | Normalize |
|---|---|---|---|---|---|---|
| Section III.B.4.a... | (1) | (2) | (3) | (4) | (5) | (6) |
| Eqn # | - | (2) | (3) | (4) | (5),(6),(7) | (9), (10) |
| Riot | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.1283 |
| Terror | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.1283 |
| Limited | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.1283 |
| Flee | 0.08 | 0.1067 | 0.1067 | 0.0829 | 0.0115 | 0.0041 |
| Defend | 0.08 | 0.60 | 0.60 | 0.06 | 0.0310 | 0.0111 |
| TS | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |

Table 13. Decision Space Calculations for W.2.

Having determined the sizes of the decision spaces for each region, the model uses the CSI and a random draw from a normal distribution to select the civilian unit's action. For this example, the CSI, IRI and decision space sizes have been used to calculate the probability of selecting a given decision. The same calculations are repeated for each civilian unit. The resulting probabilities for each unit are shown in Table 14. The detailed calculations for each unit are shown in Appendix C.

| Unit | Riot | Terror | Limited | Flee | Defend | Nothing |
|---|---|---|---|---|---|---|
| R.1 | 0.096 | 0.125 | 0.143 | 0.001 | 0.090 | 0.545 |
| R.2 | 0.021 | 0.023 | 0.025 | 0.0 | 0.163 | 0.916 |
| W.1 | 0.059 | 0.091 | 0.123 | 0.004 | 0.104 | 0.619 |
| W.2 | 0.092 | 0.140 | 0.173 | 0.006 | 0.016 | 0.574 |

Table 14. Probabilities of Selecting Civilian Actions in Step 1.

The calculated probabilities shown in Table 14 show the probability area under the normal curve with parameters CSI and IRI/25. Figure 10 graphically depicts

the areas under the normal curve. A cursory inspection shows a large amount of variability in the outcomes. Specifically, the unit R.2 shows a high probability of doing nothing (0.916). This value seems reasonable because, in step 1, the unit R.2 is the sole occupant of N2, and no other players have military forces within a one node distance. In effect, R.2 is in a very secure position and will probably feel no need to take action. The probabilities for the other units demonstrate a greater likelihood that each unit will chose some action. Again, for the circumstances of each unit, the resulting values appear reasonable: no unit has developed a strong probability of choosing an irrational action.

During this step, it was discovered that the parameter for variance in the normal distribution should be IRI / 25. An earlier attempt using IRI/10 was resulting in a uniform distribution within the interval of interest.

At this point in the model, each civilian unit would select an action, based on a random number draw against the probabilities in Table 14. For the purposes of this demonstration, Table 15 shows the arbitrary assignment of actions to each civilian unit.

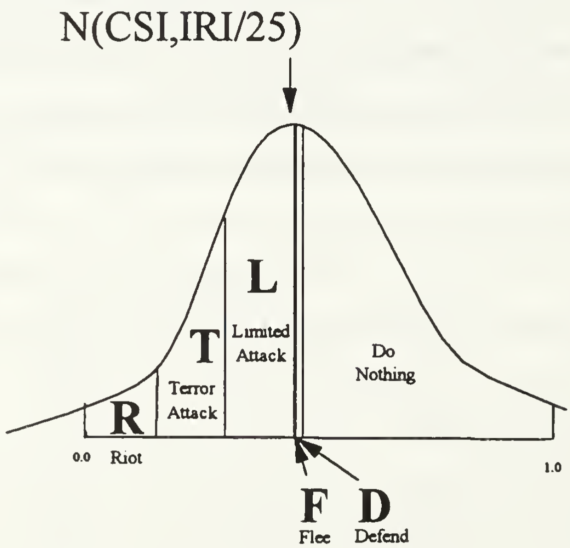



Figure 10. W.2 Unit Decision Space.

| Unit | Action |
|---|---|
| R.1 | Riot |
| R.2 | Defend |
| W.1 | Flee |
| W.2 | Defend |

Table 15. Civilian Unit Action Selections.

Given the unit actions in Table 15, each unit attempts to accomplish its assigned task. In this demonstration, it is assumed that there is no delay before beginning the task.

(1) Riot example. In the example, R.1 has chosen to riot. Therefore, the intensity, duration, and effects of the riot must be determined. Intensity, duration and attrition are determined by equations (10),(11), and (12), respectively, and are demonstrated in:

$$\begin{aligned} Intensity &= \frac{\frac{HI}{5} + (1 - CSI)}{2} + N(0,0.5) \\ &= \frac{\frac{3}{5} + (1-0.4493)}{2} + 0.0 = 0.575 \\ Duration &= \frac{(150)(0.15)}{(4)(25)(0.4493)} = 0.50 \\ Attrition &= (0.5)(0.575)(175)(0.0013) \\ &= 0.065. \end{aligned} \tag{20}$$

For cases involving random numbers the expected values are used.

The calculation results in no attrition on the participating units mainly because of the low intensity, duration, and number of people involved. This appears to be a reasonable solution.

In addition to attrition, rioting produces other model effects. For the half day that rioting was occurring, the movement rate of all units in or moving through node N1 will be reduced to one third of their normal rate. This accounts for

blockage of streets by rioters. Also, the CSI in N1 will change as a result of Table 3 in Chapter III Table 16 shows the CSI changes This change is effective immediately and permanently. The change in CSI shows that, as a result of rioting, the civil stability in the node has been reduced.

| Old CSI at N1 | Modifier | New CSI in N1 |
|---|---|---|
| 0.4493 | -(0.05)(0.5) | 0.4243 |

Table 16. CSI change in N1.

After any change in CSI, Table 6 is checked to see if any model changes are called for based on the new CSI. Finally, the production level of all classes of supply for unit R.1 is reduced to (0.75)(1-Intensity) or 0.319 of its original production rates. This reduction is due to the preoccupation of rioters with rioting instead of production, and in blocking streets and preventing other workers from getting to work. This production rate change applies to all units in the node where rioting is occurring.

(2) Defense example. In this example, the unit R.2 is defending. Therefore, the following changes in the model occur:

- Production rates are reduced to 0.35 of original rates.
- Consumption rate of "other supplies" is doubled.
- Probability of being surprised by attacking force is reduced.
- Further, the act of defending reduces the probability that another unit will chose the defending unit as a target for terrorism.

These changes are easily calculated without a numerical example.

(3) Flight example. In this example, the unit W.1 has chosen to flee from node N1. The significant decision here is to select a direction to which to flee. Table 17 shows the results of equation (16). Because of its flight, the unit W.1 will have its production set to zero until it eventually returns to node N1.

| Node | Unit | CBT Power | (HI-3) | RR |
|---|---|---|---|---|
| N1 | R.1 | 25 | 0 | 0 |
| N2 | R.2 | 50 | 0 | 0 |
| N3 | B.1<br>B.2 | 10<br>10 | 0<br>0 | 0 |
| N6 | W.2 | 15 | -2 | -30 |

Table 17. Results of Equation (16).

The model selects the minimum value of RR from Table 17 as the direction of flight. In this example, the unit W.1 chooses to flee to node N6. The zeros in Table 17 result from the neutral level of hostility of W.1 towards BLUE and RED players. The final result appears to be reasonable in that W.1 has chosen to flee to a node occupied solely by another WHITE unit.

*d. Step 2.*

Step 2 includes the transfer of supplies from the NGO logistic unit (B.1) to the NGO truck unit (B.2) and the movement of B.2 to node N1. The transfers of supplies and unit movement are well defined core FTLM model functions and will not be demonstrated here.

The movement of a BLUE unit into node N1 will initiate a new decision cycle for the unit R.1, which is occupying N1. The new decision space for R.1 is shown in Table 18. These probabilities are determined in the same way as previously shown in step 1. The detailed calculations are shown in Appendix C.

| Riot | Terror | Lim Atk | Flee | Def | Nothing |
|---|---|---|---|---|---|
| 0.091 | 0.116 | 0.132 | 0.000 | 0.123 | 0.537 |

Table 18. Step 2 Decision Probabilities for R.1.

These new probabilities are based on the Normal(0.4243,4/25) curve and represent a strong probability that unit R.1 will chose to do nothing, low probabilities of rioting, terrorist attack, limited attack or defending, and virtually no probability of flight. Based on a random number draw against the above probabilities, R.1 would select a new mission. For this demonstration, R.1 is arbitrarily assigned a mission of terrorist attack. Notice that these probabilities differ slightly from those found in Table 14 for unit R.1. These changes are due to the presence of a hostile force in the same node, and a perception by R.1 that it outnumbers the B.2 unit.

For a mission of terrorist attack, the model must determine the target and the number of casualties. To demonstrate the target selection algorithm, it is assumed that the movement of W.1 has not yet taken place and the unit B.2 has already moved into node N1. In this case, both B.2 and W.1 are eligible targets. The full decision space is divided equally between them resulting in an initial probability of 0.50 for each potential target. Then equation set (13) is applied to alter the decision space based on hostility and defensive postures. The calculations are shown in Table 19.

| | Hostility | Posture | Normalize |
|---|---|---|---|
| B.2 | (.5)(4/3)=0.67 | 0.67 | 0.57 |
| W.1 | (.5)(3/3)=0.50 | 0.50 | 0.43 |

Table 19. Calculations for Terrorist Target Selection.

A random number is drawn from a uniform[0,1] distribution and compared with the probabilities in the normalized column of Table 19. To continue the demonstration, unit B.2 is arbitrarily selected as the target.

The number of casualties resulting from the attack is determined by equation (14). Equation (14) draws a random number from a Weibull distribution. The expected value of that calculation is zero, possible indicating a random spray of automatic weapons fire, directed at the truck convoy, which failed to hit any personnel or to cause damage.

Finally, the model checks to see if the terrorists inflicted severe casualties. Since the probability of this happening is less than .002, it is unlikely that this will be chosen. If it is chosen, then a higher number of casualties will be determined based on a uniform[0, Number of personnel] distribution. This result is rounded to the nearest whole number. In this example, the terrorist attack failed to cause severe casualties.

As a result of the terrorist attack, the CSI for node N1 decreases by 0.1, in accordance with Table 3. Again, Table 2 is referenced to see if the new CSI has any immediate effect on the model. In this case, since the new CSI is below 0.40, two percent per day of the unarmed personnel for each civilian unit in node N.1 will be transformed into armed personnel. This portrays the arming and recruiting among the civilian population for self defense, as a result of the higher instability of the community. The new armed personnel are representative of new police, civilian action patrols, bandits, or private and independent, armed citizens. Although B.2 is now in N.1, it is only passing through so it is unaffected. W.1 and R.1 are changed as shown in Table 20.

| Unit | Change | New Personnel Levels | |
|---|---|---|---|
| | | Armed | Unarmed |
| R.1 | $(147)(.02)\approx 3$ | 28 | 147 |
| W.1 | $(200)(.02)=4$ | 29 | 196 |

Table 20. Calculation For Personnel Change in Node N1.

*e.* *Step 3.*

Step 3 includes the model function that takes place because of a new day. Also, units B.2 and W.1 arrive at node N6, and B.2 delivers food to unit W.2, relieving that unit's hunger. These movements, and the arrival of unit B.3 at node N2 will cause additional attrition due to starvation and the civil decision space for each unit must be recalculated, as demonstrated in step 1.

Attrition due to starvation is calculated first. This is calculated as was demonstrated in step 1. The values for β have changed because the starvation history for each unit has been advanced by one day. The resulting changes in population are shown in Table 21. The detailed calculations for this table are shown in Appendix C.

| Unit | β | KS | Population | Computed Attrition |
|---|---|---|---|---|
| R.1 | .005115 | .00510 | 173 | 2 |
| R.2 | .005115 | .00510 | 247 | 3 |
| W.1 | .015345 | .01523 | 217 | 8 |
| W.2 | .016055 | .01593 | 202 | 7 |

Table 21. Results from Equations (17) and (18) in Step 3.

The attrition results from Table 21 again cause changes in the CSI for each node. The resulting changes are shown in Table 22. The new changes in CSI in turn cause changes in other model parameters according to Table 2. In this case, nodes N1 and N6 transform unarmed personnel to armed personnel at the rate of two percent per day as was demonstrated in step 2.

| Node | Units | Casualties | Old CSI | Modifiers | New CSI |
|---|---|---|---|---|---|
| N1 | R.1 | 2 | 0.3243 | -0.00007x2 | 0.3242 |
| N2 | R.2<br>B.3 | 3<br>0 | 0.4498 | -0.00007x3 | 0.4496 |
| N3 | B.1 | 0 | 0.4500 | 0 | 0.4500 |
| N6 | W.1<br>W.2<br>B.2 | 7<br>8<br>0 | 0.3994 | -0.00007x15 | 0.3984 |

Table 22. Changes to CSI Due to Starvation in Step 3.

Table 23 shows the recalculated decision probabilities for each civilian unit. The detailed calculations are shown in Appendix C.

| Unit | Riot | Terror | Limited | Flee | Defend | Nothing |
|---|---|---|---|---|---|---|
| R.1 | 0.106 | 0.034 | 0.036 | 0.000 | 0.007 | 0.817 |
| R.2 | 0.003 | 0.003 | 0.003 | 0.004 | 0.006 | 0.981 |
| W.1 | 0.072 | 0.105 | 0.134 | 0.006 | 0.155 | 0.528 |
| W.2 | 0.072 | 0.105 | 0.134 | 0.006 | 0.155 | 0.528 |

Table 23. Probabilities of Selecting Civilian Actions in Step 3.

The new probabilities in Table 23 differ noticeably from those in Table 14. These changes are due to the changes in CSI, appearance of new units in the model, and movement of BLUE forces in the model. The values shown above appear to be reasonable probabilities. The high value of doing nothing for R.2 is due to a superior combat force (B.3) being in the same node.

Based on the above probabilities, new civilian decisions would be selected for each civilian unit. To complete the model demonstration, R.2 arbitrarily selects to perform a limited attack on B.3 in node N2. The limited attack model is basically a

Lanchester square law attrition model with high breakpoints set for the attacker. Since determining attrition and duration are well documented in [Ref. 3], further examples here are not used.

# V. SUMMARY AND FUTURE STUDY.

## A. SUMMARY.

This thesis has proposed background for an FTLM variant for modeling OOTW. It has specifically focused on modeling non-combatants in a combat theater. The key element of modeling non-combatants is modeling their decision process so that they act and react to situations in the model, and do not simply act as obstacles to field armies, as found in most combat models. This thesis described a heuristic approach to determining the decisions made by non-combatants. This model also proposed crude models of attrition from starvation, disease and collateral effects of combat. Finally, the thesis included a numerical example, which demonstrated the interaction of the many features of the non-combatant model elements.

The proposed model, OOTWTLM, appears to perform as it was intended in the limited demonstration in Chapter IV. Some of the model parameters were modified as early model demonstration attempts suggested the need. Since this is an early model effort, further study should be done to formulate more valid and verifiable model structure and parameters.

## B. TOPICS FOR FUTURE STUDY.

1. Dynamic route improvement. Using engineer units to improve trafficability along arcs by improving road surfaces and removing obstacles. Other engineer units should also have the ability to emplace obstacles and destroy roads to degrade enemy maneuver.

2. Piecemeal movement of units. Many units have some vehicles, but not enough to move their entire unit at a constant rate. The model would be improved by the addition of an algorithm that can divide a unit into small pieces, move the pieces individually, and reassemble the unit at the destination, resulting in an aggregate higher movement rate than without vehicles.

3. Fitting parameters of attrition to historical data. Many of the formulas presented in this document rely upon rough estimates, produced to demonstrate the ability of the model. A more systematic approach to discovering the true values of these parameters would improve the model.

4. Deception operations. FTLM has a unique capability to model combat operations based on perceived unit strengths and activities. That capability presents the opportunity to model deception operations, in which opponents try to deceive each other through the manipulation of each other's sensor data, and sensor targeting.

# APPENDIX A. TERRAIN.

I Introduction.

The data contained in this document are estimates from map reconnaissance and what information is available on this subject. Figure 7 shows an near-scale drawing of the area of interest in Somalia. The depicted distances between nearby nodes were exaggerated for clarity. The location in Table A-1 is based on the same references that were used to plot the node locations in Figure 11.

II. Node Descriptions and Attributes.

| | |
|---|---|
| Node# | = An arbitrary ID number for each node |
| Name | = Transliterated name of town at node. |
| Size | = Diameter of node in KM. |
| Location | = (X,Y) coordinate on a 600x600 KM grid. This is used to assist in creating a scale map and to interface with the air grid. The grid origin is in the lower left corner. |

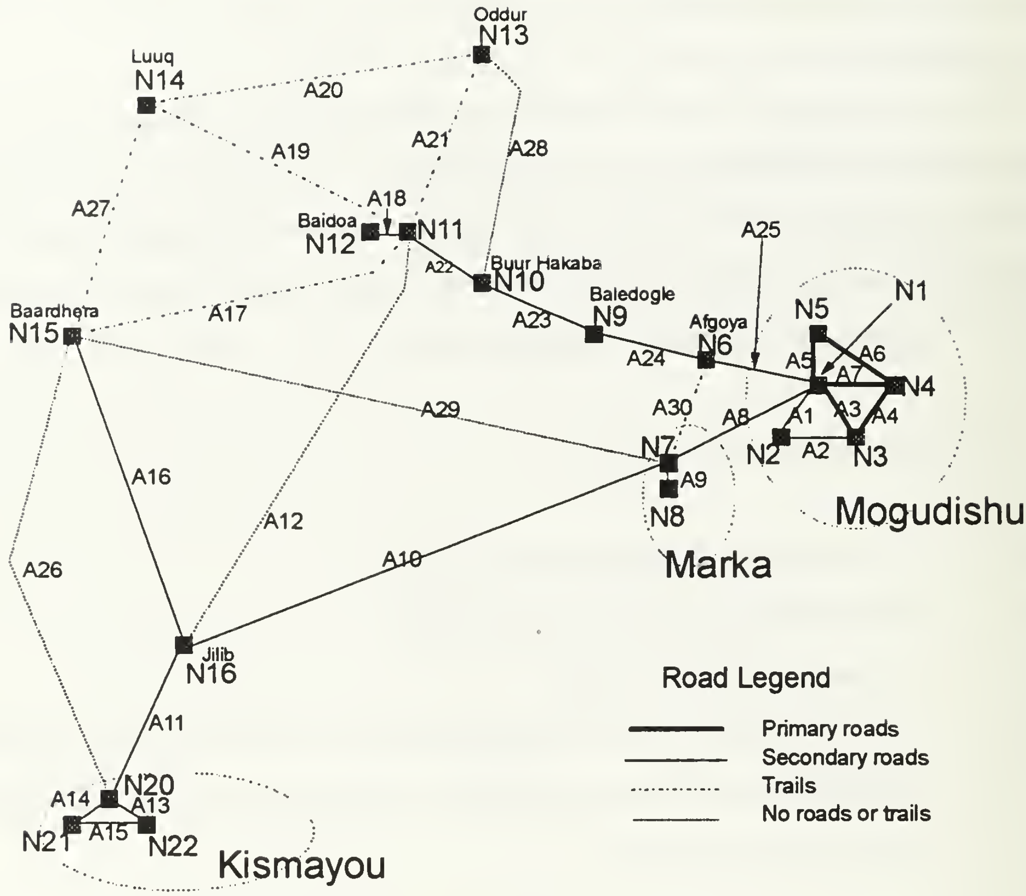



Figure 11. Arc-Node Terrain Representation.

| Node # | Name | Size (KM) | Location | InitialCSI |
|---|---|---|---|---|
| N1 | Mogudishu-K4 circle | 3 | 378,324 | .45 |
| N2 | Mogudishu-Airport | 2 | 375,318 | .45 |
| N3 | Mogudishu-Seaport | 2 | 381,318 | .45 |
| N4 | Mogudishu-East | 2 | 384,324 | .45 |
| N5 | Mogudishu-North | 2 | 378,332 | .45 |
| N6 | Afgoye | 1 | 324,342 | .40 |
| N7 | Marka | 2 | 306,258 | .45 |
| N8 | Marka-Seaport | 1 | 306,252 | .45 |
| N9 | Baledogle | 3 | 270,360 | .40 |
| N10 | Buur Hakaba | 2 | 216,396 | .38 |
| N11 | Baidoa | 3 | 180,432 | .35 |
| N12 | Baidoa-Airport | 1 | 162,432 | .35 |
| N13 | Oddur | 2 | 216,558 | .30 |
| N14 | Luuq | 1 | 54,522 | .30 |
| N15 | Baardherra | 2 | 1,360 | .38 |
| N16 | Jilib | 1 | 72,144 | .40 |
| N17 | Kismayo | 3 | 2,2 | .50 |
| N18 | Kismayo-Airport | 2 | 1,1 | .50 |
| N19 | Kismayo-Seaport | 1 | 3,1 | .50 |

Table A-1. Node Attributes.

III. Arc Attributes.

| | |
|---|---|
| Arc# | = An arbitrary ID number for each arc. |
| Nodes | = The terminals of each end of the corridor. |
| Cap | = Capacity of mobility corridor, by unit size (Width). |
| Roads | = Scale of number and quality of roads in corridor as described in [Ref. 3, p 127] . |
| Ter. | = Terrain type (open, hills, forest, urban, sea etc). |
| Cover | = Aggregated % of cover across the arc. |
| Obst | = Aggregated % of obstacles on arc. |
| Dist. | = Length of arc from node to node (KM). |

| Arc# | Nodes | | Cap | Roads | Ter. | Cover | Obst | Dist. |
|---|---|---|---|---|---|---|---|---|
| | Head | Tail | | | | | | |
| A1 | N1 | N2 | CO | 2 | URB | .7 | .05 | 1 |
| A2 | N2 | N3 | ' | 2 | ' | .7 | .05 | 1 |
| A3 | N1 | N3 | ' | 3 | ' | .7 | .05 | 1 |
| A4 | N3 | N4 | ' | 3 | ' | .7 | .05 | 1 |
| A5 | N1 | N5 | ' | 3 | ' | .7 | .05 | 1 |
| A6 | N4 | N5 | ' | 3 | ' | .7 | .05 | 1 |
| A7 | N1 | N4 | ' | 3 | ' | .7 | .05 | 1 |
| A8 | N1 | N7 | BDE | 2 | Open | .05 | .05 | 90 |
| A9 | N7 | N8 | CO | 2 | URB | .35 | .05 | 1 |
| A10 | N7 | N16 | BDE | 2 | Open | .05 | .05 | 290 |
| A11 | N16 | N17 | BDE | 2 | Open | .05 | .05 | 110 |
| A12 | N11 | N16 | BN | 0 | ' | .05 | .25 | 400 |
| A13 | N17 | N19 | CO | 2 | URB | .40 | .05 | 1 |
| A14 | N17 | N18 | CO | 2 | ' | .45 | .05 | 1 |
| A15 | N18 | N18 | CO | 2 | ' | .45 | .05 | 1 |
| A16 | N16 | N15 | BDE | 2 | Open | .08 | .05 | 300 |
| A17 | N15 | N11 | BDE | 1 | Open | .05 | .05 | 170 |
| A18 | N11 | N12 | CO | 2 | URB | .55 | .05 | 1 |
| A19 | N11 | N14 | BN | 1 | Open | .05 | .05 | 150 |
| A20 | N13 | N14 | ' | 1 | ' | .05 | .05 | 150 |
| A21 | N11 | N13 | ' | 1 | ' | .05 | .05 | 150 |
| A22 | N11 | N10 | BDE | 2 | ' | .05 | .05 | 90 |
| A23 | N10 | N9 | BDE | 2 | ' | .05 | .05 | 80 |
| A24 | N9 | N6 | BN | 2 | ' | .08 | .15 | 20 |
| A25 | N6 | N1 | BN | 2 | ' | .08 | .15 | 70 |
| A26 | N15 | N17 | CO | 0 | ' | .10 | .25 | 500 |
| A27 | N14 | N15 | BN | 1 | Hill | .15 | .10 | 150 |
| A28 | N13 | N11 | ' | 0 | Open | .20 | .25 | 240 |
| A29 | N15 | N7 | ' | 0 | ' | .05 | .25 | 350 |
| A30 | N7 | N6 | ' | 1 | ' | .05 | .05 | 70 |

Table A-2. Arc Attributes.

## APPENDIX B. ATTRITION PARTITIONING.

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# Attrition Modeling in the Presence of Decoys: An Operations-Other-Than-War Motivation

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P. A. Jacobs

## 1. INTRODUCTION

Mutual attrition on the battlefield has classically been modeled without accounting for the possible presence of false targets: decoys of low military value intended to divert opponent fire, or even the deliberate dispersal of unarmed civilians among armed and active combatants. The latter is a situation that might well occur in the operations other than war (OOTW) scenarios anticipated as one of the Major Regional Contingencies (MRCs) types into which the U.S. or joint forces might be drawn.

The issue to be addressed herein is that of understanding how Red's use of decoys, e.g. civilians for cover, influences Blue's capability to inflict attrition upon Red armed active forces, and at what expense in terms of its own attrition and the inadvertent attrition inflicted, or wasted, upon decoys. Clearly attrition of human decoys is to be strenuously avoided for humanitarian reasons, but also because of its impact on world opinion; in some circumstances such attrition might well inflame resistance to the extent that the civilian population could itself become an active threat. But in order for Blue to avoid killing Red-controlled civilians, or less politically-sensitive targets, i.e. to avoid wasting time and resources that could otherwise be directed towards targeting Red actives, some sacrifice in Blue effectiveness must be accepted.

We provide here a preliminary set of simple models for quantifying the effect of substituting discrimination for pure attrition when false targets are present. It will be seen that the effect of accounting for target discrimination power by Blue can be reduced to a nearly explicit formula that generalizes the classical Lanchesterian "square law". Elaboration to include more realistic detail induces the need for more ambitious numerical work, but the latter is still not formidable. Addition of Blue various force and Red decoy types, Blue (inanimate/non-human) decoys, stochastics, and the aforementioned change of affiliation by Red (or Blue: slaughter of Red civilians by Blue forces may induce the latter to slacken their attack) can all be modeled and ultimately quantified.

## 2. INITIAL, AND SIMPLEST, FORMULATION

Let

$R_a(t)$ = number of Red active, potentially shooting, military forces at time $t$;
$R_c(t)$ = number of Red unarmed civilians or other decoys mixed with the above at $t$;

$B(t)$ = number of Blue active armed forces at $t$.

Mechanism of combat: the Red actives deplete the Blue actives according to aimed-fire (square-law) Lanchester

$$\frac{dB}{dt} = -\rho_{RB}(t)R_a(t) \tag{1}$$

The Blue actives attempt to do the same, but must avoid killing civilians.

**2.1 Blue Shoots at First Available Red.**

If a Blue simply picks a target Red at random then, assuming military and civilians are well mixed and appear to the Blues in proportion to their numbers, he/she targets an active Red with success probability, so

$$\frac{dR_a}{dt} = -\rho_{BR}(t)s_a(t)B(t) = -\rho_{BR}(t)\left[\frac{R_a(t)}{R_a(t) + R_c(t)}\right]B(t) \tag{2}$$

Note that it is to Blue's immediate selfish advantage to discriminate between Red actives and civilians, for in the above $R_a(t)/[R_a(t) + R_c(t)$ can well be considerably less than unity, meaning that Blue only slowly reduces those shooting at him/her. Red civilians are targeted with probability $1 - s_a(t) = s_c(t)$; the results may be quite unacceptable, from Blue's viewpoint. This is a low-resolution model: differentiation between Blue force types, and coordination of fire capabilities, are important but not addressed here.

**2.2 Blue Possesses Discriminatory Powers.**

Suppose $i_{aa}$ is the probability that Blue can identify a Red active if he acquires one; $i_{ac}$ is the probability that he mis-identifies it as a civilian; $i_{ca}$, the probability that a civilian is mistaken for an active, and $i_{cc}$, the probability of correct identification of a civilian, are defined correspondingly. We hope that $i_{aa}$ and $i_{cc}$ are near unity, but there may be a cost in time for this capability; this more refined effect is modeled subsequently. Now $R_a(t)i_{aa}$ is the number of Red actives correctly identified at $t$, while $R_a(t)i_{ac}$ is the number incorrectly classed as civilians and not shot at, and $R_c(t)i_{ca}$ is the number of civilians targeted through misclassification error. Then $R_a(t)i_{aa}/[R_a(t)i_{aa} + R_a(t)i_{ac} + R_c(t)i_{ca} + R_c(t)i_{cc}]$ is the fraction (of time $dt$) spent correctly shooting at Red actives, so

the above holds because $i_{aa} + i_{ac} = 1$, $i_{ca} + i_{cc} = 1$. Notice that the identification probabilities $i_{cc}$, etc. can be made time dependent to represent changes in visibility throughout the conflict. We can also write the attrition equation for civilians:

$$\frac{dR_a(t)}{dt} = -\rho_{BR}(t)\frac{R_a(t)i_{aa}(t)}{R_a(t)(i_{aa}+i_{ac})+R_c(t)(i_{ca}+i_{cc})}B(t)$$

$$= -\rho_{BR}(t)\frac{R_a(t)i_{aa}(t)B(t)}{R_a(t)+R_c(t)} = -\rho_{BR}(t)i_{aa}(t)s_a(t)B(t);$$

$$\frac{dR_c}{dt} = -\rho_{BR}(t)\frac{R_c(t)i_{ca}(t)}{R_a(t)+R_c(t)}B(t). \tag{4}$$

The above formulations assume that the Red actives and civilians are well-mixed and hence equally likely to be found by a Blue active; however, once found, a candidate target can be assessed for relevance but with error. For now we slough off the time-dependent aspects of this process. A model with more Blue states can handle this aspect more properly; see Section 3.

To move towards actual solutions, divide (3) by (4):

$$\frac{\frac{dR_a}{dt}}{\frac{dR_c}{dt}} = \frac{-\rho_{BR}(t)\frac{R_a(t)i_{aa}(t)}{R_a(t)+R_c(t)}B(t)}{-\rho_{BR}(t)\frac{R_c(t)i_{ca}(t)}{R_a(t)+R_c(t)}B(t)} = \frac{R_a(t)i_{aa}(t)}{R_c(t)i_{ca}(t)}, \tag{5}$$

so upon division

$$\frac{\left(\frac{dR_a}{dt}\right)}{R_a(t)} \Bigg/ \frac{\left(\frac{dR_c}{dt}\right)}{R_c(t)} = \frac{i_{aa}(t)}{i_{ca}(t)}. \tag{6}$$

For simplicity drop the $i$-time dependency; now easy explicit integration is possible:

$$\ln R_a(t) - \ln R_a(0) = \left(\frac{i_{aa}}{i_{ca}}\right)(\ln R_c(t) - \ln R_c(0)) . \tag{7}$$

From this,

$$R_c(t) = R_c(0) \cdot \left(R_a(t)/R_a(0)\right)^{i_{ca}/i_{aa}} \quad . \tag{8}$$

Now plug this into equation (3):

$$\frac{dR_a}{dt} = -\rho_{BR}(t)\frac{R_a(t)i_{aa}B(t)}{R_a(t) + R_c(0)\left(R_a(t)/R_a(0)\right)^{i_{ca}/i_{aa}}} \quad . \tag{9}$$

Divide (1) by (9): we come up with an equation that relates $B(t)$ and $R_a(t)$ *that can be integrated explicitly*. We anticipate that a "generalized square law" will show itself (no disappointment here!).

Proceed to solve for $R_a$ in terms of $B$:

$$\frac{dR_a/dt}{dB/dt} = \frac{-\rho_{BR}(t)\dfrac{R_a(t)i_{aa}B(t)}{R_a(t) + \left(R_c(0)/R_a(0)^{i_{ca}/i_{aa}}\right)\left(R_a(t)\right)^{i_{ca}/i_{aa}}}}{-\rho_{RB}(t)R_a(t)}. \tag{10}$$

Rearranging,

$$\left(R_a(t) + \left(\frac{R_c(0)}{\left(R_a(0)\right)^{i_{ca}/i_{aa}}}\right)\left(R_a(t)\right)^{i_{ca}/i_{aa}}\right)dR_a(t) = \frac{\rho_{BR}}{\rho_{RB}}i_{aa}B(t)dB. \tag{11}$$

Assume that $\rho_{BR}(t)/\rho_{RB}(t)$ is independent of $t$ and integrate and finally get

$$\begin{aligned}&\frac{R_a^2(t)}{2} - \frac{R_a^2(0)}{2} + \left(\frac{R_c(0)}{\left(R_a(0)\right)^{i_{ca}/i_{aa}}}\right)\left[\frac{R_a(t)^{\left(i_{ca}/i_{aa}\right)+1}}{\left(i_{ca}/i_{aa}\right)+1} - \frac{R_a(0)^{\left(i_{ca}/i_{aa}\right)+1}}{\left(i_{ca}/i_{aa}\right)+1}\right] \\ &= \frac{\rho_{BR}}{\rho_{RB}}i_{aa}\left[\frac{B^2(t)}{2} - \frac{B^2(0)}{2}\right].\end{aligned} \tag{12}$$

This is the generalized square law. Notice that if $R_c(0) = 0$ we are back to the original square law, immortalized in song and story.

Illustration 1: $i_{ca} = i_{aa}$, $R_c(0) = R_a(0)$

This is a pessimistic case for Blue, who has no discriminatory power. But the result is simple:

$$\frac{R_a^2(t)}{2} - \frac{R_a^2(0)}{2} + \left[\frac{R_a^2(t)}{2} - \frac{R_a^2(0)}{2}\right] = \frac{\rho_{BR}}{\rho_{RB}} i_{aa}\left[\frac{B^2(t)}{2} - \frac{B^2(0)}{2}\right]$$

or

$$R_a^2(0) - R_a^2(t) = \left(\frac{\rho_{BR}}{\rho_{RB}}\right)\left(\frac{i_{aa}}{2}\right)\left[B^2(0) - B^2(t)\right], \tag{13}$$

which is a new square-law result.

The above is precisely the same equation that would occur if there were no civilians ($R_c(0) = 0$), but with $\rho_{BR}$, the attrition rate of Blue *vs.* Red, replaced — *reduced* — to $\rho_{BR}\, i_{ad}/2$. In this case the presence of civilians has diluted the Blue force's effectiveness by $i_{ad}/2$, i.e. by at least a factor of two. Furthermore, civilians are still getting targeted and presumably killed since $i_{ca} = i_{aa}$, which is unrealistic. This disadvantage is overcome by sharpening Blue's perception so as to reduce $i_{ca}$ well below $i_{aa}$, which would allow return (nearly) to classical attrition formulas. Otherwise, more Blue forces would be needed to achieve desired results.

Illustration 2: $i_{ca} = 0$

This is optimistic for Red decoys: they are never targeted. Note that (12) becomes

$$\frac{R_a^2(0)}{2} - \frac{R_a^2(t)}{2} + R_c(0)\left[R_a(0) - R_a(t)\right] = \frac{\rho_{BR}}{\rho_{RB}} i_{aa}\left[\frac{B^2(0)}{2} - \frac{B^2(t)}{2}\right]. \tag{14}$$

From this it is apparent that surviving Red attacker number, $R_a(t)$, increases with $R_c(0)$, initial decoy supply, as is intuitive: the presence of Red decoys still interferes with Blue's effectiveness, even though none are actually engaged.

## 3. A MORE COMPLEX FORMULATION

Recognition of the need to spend significant time to avoid targeting civilians or other decoys requires a somewhat expanded model. Thus we extend the Blue state space: $B_a(t)$ is the number of Blue *attackers* or shooters, while $B_s(t)$ is the number of *seekers*, i.e. those who have stopped shooting, are in the process of locating a new potential target, and are taking time to verify that it is indeed an attacker. The inclusion of this stage explicitly accounts for the above-mentioned time, at least initially and crudely.

Let

$B_a(t)$= number of blue forces actually pursuing attack on Red attackers, and

$B_s(t)$= number of Blue forces in search of appropriate Red targets, i.e. attackers rather than civilians.

Now if $\xi$ is the effective search rate of a Blue seeker,

$$\frac{dB_a}{dt} = \xi(R_a(t) + R_c(t))B_s(t) - \rho_{BR}B_a(t) - \rho_{RB}\left(\frac{B_a(t)}{B_a(t) + B_s(t)}\right)R_a(t) \; ; \tag{15}$$

this accounts for the increase of Blue actives by reason of Blue seekers finding Reds, the decrease of Blue actives by, first, termination of engagements with Reds and, second, the attrition of Blue actives by Reds. Next, for Blue seekers, we get

$$\frac{dB_s}{dt} = \rho_{BR}B_a(t) - \xi(R_a(t) + R_c(t))B_s(t) - \rho_{RB}\left(\frac{B_s(t)}{B_a(t) + B_s(t)}\right)R_a(t) \; ; \tag{16}$$

the first two terms of which mirror corresponding gains and losses in (1), and the last is a Blue seeker attrition term. At the moment we do not endow Red with the power, or desire, to discriminate between Blue actives and seekers. Note that if (15) and (16) are added we get back $dB/dt = \rho_{RB}R_a(t)$, where $B = B_a + B_s$. Otherwise the two nonlinear equations resist explicit solution. Here is an

**Approximation**.

Argue that the seeking action is relatively rapid so $B_s(t)$ is *quasi-stationary*: set the derivative $dB_s/dt = 0$ and solve for $B_s(t)$; see Segel and Slemrod (1989) for discussion. The above is explicitly possible (a quadratic in $B_s(t)$ results) but go further by (temporarily) neglecting the attrition-of-$B_s(t)$ terms. This is equivalent to assuming high, but not infinite, rate of Blue search completion ($\xi$) and attrition ($\rho_{BR}$) as compared to the attrition of Red on Blue seekers. Then approximately

$$B_s(t) = \left(\rho_{BR}/\xi\right)\frac{B_a(t)}{R_a(t) + R_c(t)} \; . \tag{17}$$

Now substitute into (15) to get

$$
\begin{aligned}
\frac{dB_a}{dt} &= -\rho_{RB}\frac{B_a(t)R_a(t)}{B_a(t) + \left(\rho_{BR}/\xi\right)\left(\frac{B_a(t)}{R_a(t)+R_c(t)}\right)} \\
&= -\rho_{RB}\left(\frac{R_a(t) + R_c(t)}{R_a(t) + R_c(t) + \left(\rho_{BR}/\xi\right)}\right)R_a(t)
\end{aligned}
\tag{18}
$$

Then use of (8) provides that

$$
dR_a/dt = \frac{-\rho_{BR}\dfrac{R_a(t)i_{aa}B_a(t)}{R_a(t)+\left(R_c(0)/R_a(0)^{i_{ca}/i_{aa}}\right)}}{-\rho_{BR}\left(\dfrac{R_a(t)+R_c(0)\left(R_a(t)/R_a(0)\right)^{i_{ca}/i_{aa}}}{R_a(t)+R_c(0)\left(R_a(t)/R_a(0)\right)^{i_{ca}/i_{aa}}+\rho_{BR}/\xi}\right)R_a(t)}
\tag{19}
$$

or

$$
\left[\frac{\left(R_a(t) + R_c(0)\left(R_a(t)/R_a(0)\right)^{i_{ca}/i_{aa}}\right)^2}{R_a(t) + R_c(0)\left(R_a(t)/R_a(0)\right)^{i_{ca}/i_{aa}} + \rho_{BR}/\xi}\right]dR_a = \frac{\rho_{BR}}{\rho_{RB}}i_{aa}B_a(t)dB_a(t).
\tag{20}
$$

If $\rho_{BR}/\xi$ is assumed small (not zero) and a two-term Taylor's series approximation is accepted,

$$
\left[R_a(t)+R_c(0)\left(R_a(t)/R_a(0)\right)^{i_{ca}/i_{aa}} - \rho_{BR}/\xi\right]dR_a \approx \frac{\rho_{BR}}{\rho_{RB}}i_{aa}B_a dB_a
\tag{21}
$$

and the result becomes

$$
\begin{aligned}
\frac{R_a^2(t)}{2} - \frac{R_a^2(0)}{2} + \frac{R_c(0)}{\left(R_a(0)\right)^{i_{ca}/i_{aa}}} \left[ \frac{R_a(t)^{i_{ca}/i_{aa}+1}}{i_{ca}/i_{aa}+1} - \frac{R_a(0)^{i_{ca}/i_{aa}+1}}{i_{ca}/i_{aa}+1} \right] & \\
- \frac{\rho_{BR}}{\xi} \left[ R_a(t) - R_c(0) \right] & \\
\cong \frac{\rho_{BR}}{\rho_{RB}} i_{aa} \left[ \frac{B_a^2(t)}{2} - \frac{B_a^2(0)}{2} \right] . &
\end{aligned}
\qquad \textbf{(22)}
$$

## References


Segel, L. A., and Slemrod, M. (1989) "The quasi-steady-state assumption: a case study in perturbation". *SIAM REVIEW*, Vol. 31, No. 3, pp. 446_477.

# APPENDIX C. DETAILED CALCULATIONS FROM NUMERICAL EXAMPLE.

**Step 1 Decision Space Calculations**

| | | Init | Hold Ter. | Hostility | SelfPres | p-Attack | Normalize | Cum | N(0.443,0.16) Normal | Probs |
|---|---|---|---|---|---|---|---|---|---|---|
| | Riot | 0.08 | 0.08 | 0.08 | 0.72 | 0.72 | 0.147252 | 0.147252 | 0.229841 | 0.095802 |
| R.1 | Terror | 0.08 | 0.08 | 0.08 | 0.72 | 0.72 | 0.147252 | 0.294504 | 0.355229 | 0.125388 |
| in N1 | Limited | 0.08 | 0.08 | 0.08 | 0.72 | 0.72 | 0.147252 | 0.441755 | 0.498759 | 0.14353 |
| csi=.443 | Flee | 0.08 | 0.053333 | 0.053333 | 0.013333 | 0.001378 | 0.000282 | 0.442037 | 0.49904 | 0.000281 |
| | Defend | 0.08 | 0.12 | 0.12 | 0.12 | 0.4464 | 0.091296 | 0.533333 | 0.589334 | 0.090295 |
| | TS | 0.4 | 0.4 | 0.533333 | 0.533333 | 0.533333 | | | 0.134039 | |
| | | | | | SUMS | 2.607778 | 0.533333 | | Do Nothing | 0.544705 |

| R.2 | | Init | Hold Ter. | Hostility | SelfPres | p-Attack | Normalize | Cum | N(0.44979,0.16) NORMAL | Probs |
|---|---|---|---|---|---|---|---|---|---|---|
| in N2 | Riot | 0.08 | 0.08 | 0.08 | 0.72 | 0.72 | 0.036813 | 0.036813 | 0.150932 | 0.020527 |
| CSI=0.4497 | Terror | 0.08 | 0.08 | 0.08 | 0.72 | 0.72 | 0.036813 | 0.073626 | 0.173504 | 0.022571 |
| | Limited | 0.08 | 0.08 | 0.08 | 0.72 | 0.72 | 0.036813 | 0.110439 | 0.198114 | 0.02461 |
| | Flee | 0.08 | 0.053333 | 0.053333 | 0.013333 | 0.001378 | 0.00007 | 0.110509 | 0.198163 | 0.000049 |
| | Defend | 0.08 | 0.12 | 0.12 | 0.12 | 0.4464 | 0.022824 | 0.133333 | 0.214431 | 0.016268 |
| | TS | 0.4 | 0.4 | 0.133333 | 0.133333 | 0.133333 | | | 0.130406 | |
| | | | | | SUMS | 2.607778 | 0.133333 | | Do Nothing | 0.915975 |

| W.1 | | Init | Hold Ter. | Hostility | SelfPres | p-Attack | Normalize | Cum | N(0.443,0.08) NORMAL | Probs |
|---|---|---|---|---|---|---|---|---|---|---|
| in N1 | Riot | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.106616 | 0.106616 | 0.117162 | 0.058516 |
| CSI=0.443 | Terror | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.106616 | 0.213233 | 0.208295 | 0.091134 |
| | Limited | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.106616 | 0.319849 | 0.331634 | 0.123339 |
| | Flee | 0.08 | 0.106667 | 0.106667 | 0.082857 | 0.009998 | 0.002961 | 0.32281 | 0.335442 | 0.003807 |
| | Defend | 0.08 | 0.06 | 0.06 | 0.06 | 0.26064 | 0.07719 | 0.4 | 0.439582 | 0.104141 |
| | TS | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | | | 0.058646 | |
| | | | | | SUMS | 1.350638 | 0.4 | | Do Nothing | 0.619064 |

| W.2 | | Init | Hold Ter. | Hostility | SelfPres | p-Attack | Normalize | Cum | N(0.3944,0.08) NORMAL | Probs |
|---|---|---|---|---|---|---|---|---|---|---|
| in N6 | Riot | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.128288 | 0.128288 | 0.173392 | 0.091795 |
| CSI=.3944 | Terror | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.128288 | 0.256577 | 0.31303 | 0.139639 |
| | Limited | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.128288 | 0.384865 | 0.486554 | 0.173523 |
| | Flee | 0.08 | 0.106667 | 0.106667 | 0.082857 | 0.011478 | 0.00409 | 0.388955 | 0.492321 | 0.005767 |
| | Defend | 0.08 | 0.06 | 0.06 | 0.06 | 0.030993 | 0.011045 | 0.4 | 0.507898 | 0.015577 |
| | TS | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | | | 0.081596 | |
| | | | | | SUMS | 1.122471 | 0.4 | | Do Nothing | 0.573698 |

**Step 2 Decision Space Calculations**

| | | Init | Hold Ter. | Hostility | SelfPres | p-Attack | Normalize | Cum | N(0.4243,0.16) Normal | Probs |
|---|---|---|---|---|---|---|---|---|---|---|
| | Riot | 0.08 | 0.08 | 0.08 | 0.6 | 0.6 | 0.136104 | 0.136104 | 0.235612 | 0.09121 |
| R.1 | Terror | 0.08 | 0.08 | 0.08 | 0.6 | 0.6 | 0.136104 | 0.272208 | 0.351887 | 0.116276 |
| in N1 | Limited | 0.08 | 0.08 | 0.08 | 0.6 | 0.6 | 0.136104 | 0.408312 | 0.484059 | 0.132171 |
| csi=.4243 | Flee | 0.08 | 0.053333 | 0.053333 | 0.007111 | 0.001303 | 0.000296 | 0.408608 | 0.484353 | 0.000295 |
| | Defend | 0.08 | 0.12 | 0.12 | 0.12 | 0.54984 | 0.124726 | 0.533333 | 0.607413 | 0.12306 |
| | TS | 0.4 | 0.4 | 0.533333 | 0.533333 | 0.533333 | | | 0.144402 | |
| | | | | | SUMS | 2.351143 | 0.533333 | | Do Nothing | 0.536989 |

## Step 3 Decision Space Calculations

| | | Init | Hold Ter. | Hostility | SelfPres | p-Attack | Normalize | Cum | N(0.3242,0.16) Normal | Probs |
|---|---|---|---|---|---|---|---|---|---|---|
| | Riot | 0.08 | 0.08 | 0.08 | 0.72 | 0.72 | 0.041659 | 0.041659 | 0.239984 | 0.105945 |
| R.1 | Terror | 0.08 | 0.08 | 0.08 | 0.72 | 0.72 | 0.041659 | 0.083317 | 0.273518 | 0.033534 |
| in N1 | Limited | 0.08 | 0.08 | 0.08 | 0.72 | 0.72 | 0.041659 | 0.124976 | 0.309221 | 0.035703 |
| csi=.3242 | Flee | 0.08 | 0.053333 | 0.053333 | 0.013333 | 0.000444 | 0.000026 | 0.125002 | 0.309243 | 0.000023 |
| | Defend | 0.08 | 0.12 | 0.12 | 0.12 | 0.144 | 0.008332 | 0.133333 | 0.316622 | 0.007378 |
| | TS | 0.4 | 0.4 | 0.133333 | 0.133333 | 0.133333 | | | 0.208826 | |
| | | | | | SUMS | 2.304444 | 0.133333 | | Do Nothing | 0.817417 |

| | | Init | Hold Ter. | Hostility | SelfPres | p-Attack | Normalize | Cum | N(0.4496,0.16) NORMAL | Probs |
|---|---|---|---|---|---|---|---|---|---|---|
| | Riot | 0.08 | 0.08 | 0.08 | 0.12 | 0.12 | 0.006135 | 0.006135 | 0.133788 | 0.003282 |
| R.2 | Terror | 0.08 | 0.08 | 0.08 | 0.12 | 0.12 | 0.006135 | 0.012271 | 0.137126 | 0.003338 |
| in N2 | Limited | 0.08 | 0.08 | 0.08 | 0.12 | 0.12 | 0.006135 | 0.018406 | 0.140521 | 0.003394 |
| CSI=0.4496 | Flee | 0.08 | 0.053333 | 0.053333 | 0.08 | 0.1272 | 0.006504 | 0.02491 | 0.14418 | 0.00366 |
| | Defend | 0.08 | 0.12 | 0.12 | 0.12 | 0.1908 | 0.009755 | 0.034666 | 0.14979 | 0.005609 |
| | TS | 0.4 | 0.4 | 0.533333 | 0.533333 | 0.533333 | | | 0.130507 | |
| | | | | | SUMS | 0.678 | 0.034666 | | Do Nothing | 0.980717 |

| | | Init | Hold Ter. | Hostility | SelfPres | p-Attack | Normalize | Cum | N(0.3984,0.08) NORMAL | Probs |
|---|---|---|---|---|---|---|---|---|---|---|
| | Riot | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.098042 | 0.098042 | 0.144134 | 0.064651 |
| W.1 | Terror | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.098042 | 0.196084 | 0.237213 | 0.093078 |
| in N6 | Limited | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.098042 | 0.294125 | 0.356188 | 0.118975 |
| CSI=0.3984 | Flee | 0.08 | 0.106667 | 0.106667 | 0.082857 | 0.014362 | 0.003911 | 0.298037 | 0.361355 | 0.005167 |
| | Defend | 0.08 | 0.06 | 0.06 | 0.06 | 0.3744 | 0.101963 | 0.4 | 0.502257 | 0.140901 |
| | TS | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | | | 0.079483 | |
| | | | | | SUMS | 1.468762 | 0.4 | | Do Nothing | 0.577226 |

| | | Init | Hold Ter. | Hostility | SelfPres | p-Attack | Normalize | Cum | N(0.3984,0.08) NORMAL | Probs |
|---|---|---|---|---|---|---|---|---|---|---|
| | Riot | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.098042 | 0.098042 | 0.144134 | 0.064651 |
| W.2 | Terror | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.098042 | 0.196084 | 0.237213 | 0.093078 |
| in N6 | Limited | 0.08 | 0.08 | 0.08 | 0.36 | 0.36 | 0.098042 | 0.294125 | 0.356188 | 0.118975 |
| CSI=.3984 | Flee | 0.08 | 0.106667 | 0.106667 | 0.082857 | 0.014362 | 0.003911 | 0.298037 | 0.361355 | 0.005167 |
| | Defend | 0.08 | 0.06 | 0.06 | 0.06 | 0.3744 | 0.101963 | 0.4 | 0.502257 | 0.140901 |
| | TS | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | | | 0.079483 | |
| | | | | | SUMS | 1.468762 | 0.4 | | Do Nothing | 0.577226 |

## Hunger Attrition Calculations

*Step 1:*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Beta 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| gamma | 0.0001 | 0.0002 | 0.0004 | 0.0008 | 0.0016 | 0.0032 | 0.006 | 0.013 | 0.026 | 0.051 | |
| R.1 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | |
| | 5.000E-06 | 1E-05 | 0.00002 | 0.00004 | 0.00008 | 0.0002 | 0.000 | 0.001 | 0.001 | 0.003 | 0.005115 |
| R.2 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | |
| | 5.000E-06 | 1E-05 | 0.00002 | 0.00004 | 0.00008 | 0.0002 | 0.000 | 0.001 | 0.001 | 0.003 | 0.005115 |
| W.1 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | |
| | 0.000015 | 3E-05 | 0.00006 | 0.00012 | 0.00024 | 0.0005 | 0.001 | 0.002 | 0.004 | 0.008 | 0.015345 |
| W.2 | 0.25 | 0.25 | 0.25 | 0.2 | 0.2 | 0.2 | 0.15 | 0.15 | 0.15 | 0.15 | |
| | 0.000025 | 5E-05 | 0.0001 | 0.00016 | 0.00032 | 0.0006 | 0.001 | 0.002 | 0.004 | 0.008 | 0.015695 |

| | Armed Pers | Unarmed | Beta | 1-e{-beta} | Attrit by Hunger |
|---|---|---|---|---|---|
| B.1 | 1 | 50 | | | |
| B.2 | 1 | 50 | | | |
| B.3 | 750 | 2 | 0 | 0 | 0 |
| R.1 | 25 | 150 | 0.005115 | 0.005102 | 2 |
| R.2 | 50 | 200 | 0.005115 | 0.005102 | 3 |
| W.1 | 25 | 200 | 0.015345 | 0.015228 | 8 |
| W.2 | 10 | 200 | 0.015695 | 0.015572 | 8 |

*Step 3:*

| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Beta 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| gamma | 0.0001 | 0.0002 | 0.0004 | 0.0008 | 0.0016 | 0.0032 | 0.006 | 0.013 | 0.026 | 0.051 | |
| R.1 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | |
| | 5.000E-06 | 1E-05 | 0.00002 | 0.00004 | 0.00008 | 0.0002 | 0.000 | 0.001 | 0.001 | 0.003 | 0.005115 |
| R.2 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | |
| | 5.000E-06 | 1E-05 | 0.00002 | 0.00004 | 0.00008 | 0.0002 | 0.000 | 0.001 | 0.001 | 0.003 | 0.005115 |
| W.1 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | |
| | 0.000015 | 3E-05 | 0.00006 | 0.00012 | 0.00024 | 0.0005 | 0.001 | 0.002 | 0.004 | 0.008 | 0.015345 |
| W.2 | 0.25 | 0.25 | 0.25 | 0.25 | 0.2 | 0.2 | 0.2 | 0.15 | 0.15 | 0.15 | |
| | 0.000025 | 5E-05 | 0.0001 | 0.0002 | 0.00032 | 0.0006 | 0.001 | 0.002 | 0.004 | 0.008 | 0.016055 |

| | Armed Pers | Unarmed | Beta | 1-e{-beta} | Attrit by Hunger |
|---|---|---|---|---|---|
| B.1 | 1 | 50 | | | |
| B.2 | 1 | 50 | | | |
| B.3 | 750 | 2 | 0 | 0 | 0 |
| R.1 | 25 | 148 | 0.005115 | 0.005102 | 2 |
| R.2 | 50 | 197 | 0.005115 | 0.005102 | 3 |
| W.1 | 25 | 192 | 0.015345 | 0.015228 | 8 |
| W.2 | 10 | 192 | 0.016055 | 0.015927 | 7 |

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